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UNITED STATES
DEPARTMENT OF THE INTERIOR
J. A. KRUG, SECRETARY

BUREAU OF MINES
JAMES BOYD, DIRECTOR

INFORMATION CIRCULAR

REPORT OF PETROLEUM AND NATURAL-GAS DIVISION

FISCAL YEAR 1945

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

REPORT OF PETROLEUM AND NATURAL-GAS DIVISION, FISCAL YEAR 1945[1]

By R. A. Cattell,[2] and others

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[1] The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used. "Reprinted from the Bureau of Mines Information Circular 7505."

[2] Chief, Petroleum and Natural Gas Division, Bureau of Mines, Washington, D.C.

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SUMMARY

With the activities of the Petroleum and Natural Gas Division geared chiefly to problems directly connected with the war effort, the emphasis of the work under oil and gas development and production was to make engineering studies of selected reservoirs for the Petroleum Administration for War, to determine the extractable quantities of components in them, and to study the characteristics of these components for use in the manufacture of aviation gasoline and other products. The needs of the Petroleum Administration for War and the operators for specific data from gas-condensate fields were fulfilled, and, in addition, engineering data along lines of a forward-looking program of research on reservoir behavior were collected, which should be of great value in the postwar period. It is planned to publish many of these data as soon as conditions permit.

The work of the Secondary Recovery Section had as its objectives increasing the rate of production of crude petroleum and, which is more important, preventing the premature abandonment of wells in "stripper" and marginal areas. According to the National Survey of Stripper Wells by the National Stripper Well Association in cooperation with the Interstate Oil Compact

Commission, a total of 67,460 stripper wells was abandoned from January 1, 1935, to July 1, 1942, inclusive, with an estimated loss in proved reserves of approximately 216 million barrels. This survey also indicates that over 1.2 billion barrels of oil would be recovered by primary production from more than 290,000 stripper wells then in operation, and an additional 2.5 billion barrels of oil could be recovered from them by secondary production methods.

The work of the Chemistry and Refining Section was oriented towards the optimum utilization of crude oils in the manufacture of aviation fuels for spark-ignition and jet-propulsion engines. The work involved intensive studies of superfractionation, hydrocarbon analysis, and the engine testing of fuels. Particular attention was given to the effect of sulfur compounds in the crude oils and in the fuels made from them.

The research on thermodynamics is concerned with the experimental determination of precise and accurate values of the fundamental thermodynamic constants of pure hydrocarbons and related compounds. The data obtained in these investigations will be utilized for devising and improving chemical processes in which petroleum hydrocarbons are the raw materials. Without such data, much time and expensive material and equipment may be wasted in attempts to obtain reactions under conditions that the laws of thermodynamics rule out of consideration. Thermodynamic data are useful and required in the petroleum industry for calculations of heat balances in the design of furnaces, fractionating towers, and heat-transfer equipment. It is of utmost importance, also, to know the heat requirements of cracking and other chemical reactions so that heat may be supplied or dissipated in the proper proportions. These needs for thermodynamic data are being recognized more and more by petroleum-refining engineers.

The responsibility for the production of helium for the Navy, the Army, other governmental agencies and non-Federal users is vested in the Bureau of Mines by an Act of Congress (50 Stat. 885; 50 U.S.C. 161-166). The Helium Subdivision of the Petroleum and Natural Gas Division continued to meet all demands for helium.

ACKNOWLEDGMENTS

The preparation of this Information Circular is based upon information supplied by each of the field offices and stations of the Division under the supervision of the following men:

H. C. Fowler, Petroleum Experiment Station, Bartlesville, Okla.
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Special acknowledgment is given to H. C. Fowler for correlating the material contributed by the various field stations and offices relating to petroleum and natural gas.

OIL AND GAS DEVELOPMENT AND PRODUCTION

Production engineers of the Bureau of Mines continued their special war assignments. Those of the Petroleum Experiment Station at Bartlesville, Okla., collaborated with engineers from the Dallas, Tex., Petroleum Field Office in obtaining and analyzing reservoir and laboratory data pertaining to gas-condensate fields. These data include correlations of sandstone and other porous reservoir rocks comprising the producing zones, evaluations of the productivity of wells, and determinations of the characteristics of the fluids from gas-condensate fields. All of these and many other data must be considered before decisions can be reached regarding the engineering and economic feasibility of a cycling program for a given reservoir.

Restricted reports, which were furnished only to the Petroleum Administration for War and to the operators of the fields under study during the fiscal year, included engineering studies of the Seeligson field, Jim Wells and Kleberg Counties, Tex., the Lake Creek field, Montgomery County, Tex., and the Paradis field, St. Charles Parish, La.; also determinations of the flow characteristics and the properties of fluids from condensate reservoirs in the Old Ocean field, Brazoria and Matagorda Counties, Tex., and the Seeligson field, Jim Wells and Kleberg Counties, Tex. A report on wellhead sampling of flowing gas-condensate wells for the Committee on High-Pressure Sampling of the Natural Gasoline Association of America also was prepared.

Other studies, which not only have a direct bearing on the war but which will also be of later benefit to the country and the petroleum industry, were conducted. One of these is an outgrowth of research on the characteristics of fluids from gas-condensate reservoirs. Because of serious corrosion of tubing and wellhead equipment in high-pressure and high-temperature wells, research was undertaken to determine the corrosive effects of carbon dioxide gas and of organic acids contained in the condensed water vapor coming from reservoirs of this type and to determine means of eliminating the corrosion.

Another activity was the study of reservoir pressures and temperatures and the analysis of samples of reservoir oils collected in special sampling devices near the bottoms of wells. Shrinkage, gas liberation, and other physical properties of oil in the reservoir were determined. This type of work was emphasized in Naval Petroleum Reserve No. 1, Elk Hills, Calif., where engineers of the Petroleum Experiment Station worked in close conjunction with engineers of the San Francisco Petroleum Field Office. Production engineers of the Petroleum and Oil Shale Experiment Station, Laramie, Wyo., conducted similar studies in Rocky Mountain fields. Still another activity that should find wide application in the post-war period was the use of a special drilling technique and the use of diamond core bits in limestone formations. The experiments that resulted in the development of this technique were conducted in the West Edmond, Okla., field.

Several problems on which work has been done during the fiscal year, with brief outlines of their scope and the progress that has been made, are described in the following sections:

Sampling Condensate Wells

The portable laboratory used by the Bureau of Mines in studies of gas-condensate reservoirs is shown in fig. 1. The apparatus for investigation of hydrocarbon fluid properties is permanently mounted in the truck body, and the truck stands near the flowing well while tests are in progress. The rear end of the interior of the truck body is shown in fig. 2. The apparatus is essentially a duplicate of the full-scale equipment at many gas-condensate wells, with the exception of the pump in the foreground, which provides test pressures greater than wellhead pressures, and a steam-heated oil bath (object with gray sidewalls), which is used to control temperatures in the range 70° to 280° F. A small liquid accumulator corresponding to the full-scale separator is controlled by a piston gage-actuated diaphragm valve.

Throughout the Bureau of Mines studies of gas-condensate reservoirs, samples of the flowing fluids have been obtained at the wellhead by means of a small tube that leads to the liquid accumulator in the portable laboratory. The rate at which the fluids were withdrawn from the flowing well stream was determined by a careful check on the rate of accumulation of the fluids (liquid:gas ratio) in the full-scale separator and stock tanks. The High-pressure Sampling Committee of the Natural Gasoline Association of America has carried on numerous field tests during the last several years to develop means and methods of sampling wells accurately without the use of full-scale separators. To give the committee the benefit of the experience of the Bureau in sampling wells, a report[3] on wellhead sampling of flowing gas-condensate wells was prepared for presentation at a committee meeting and for later publication in the transactions of the association.

Windowed Cell

Because of the high velocities involved and the cooling effect in reducing high-pressure gas to low pressures, it has been impossible, with the equipment in the portable laboratory, to study liquid:gas ratios of condensate wells at pressures lower than 150 p.s.i. and at temperatures lower than 70° F. In addition to other difficulties, gas hydrates in the fluid will freeze and prevent flow. To overcome this obstacle, Bureau engineers designed a high-pressure windowed cell. The gas and condensate will be placed in this cell, which will be operated at temperatures as low as 40° or 50° below zero. The data collected in the portable laboratory during field tests at pressures up to 5,800 p.s.i. and at temperatures over the range 70° to 280° F. can be extended by the use of this cell to very low temperatures and possibly provide information on the critical pressure and temperature of the fluid.

Gas-condensate wells producing from reservoirs having low permeability characteristics generally will not produce at a steady rate over a long enough period to test the well with the portable laboratory. From such wells, separator samples of liquid and gas will be collected simultaneously after the well has been produced for a period of time, and the liquid:gas ratios under a wide range of pressures and temperatures will be determined on mixtures of the samples in the windowed cell.

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[3] Eilerts, C. Kenneth, and others, Wellhead Sampling of Flowing Gas-Condensate Wells: Proceedings, 1945-46 Conventions, Natural Gasoline Association of America, December 1946, pp. 125-148, 12 figs.

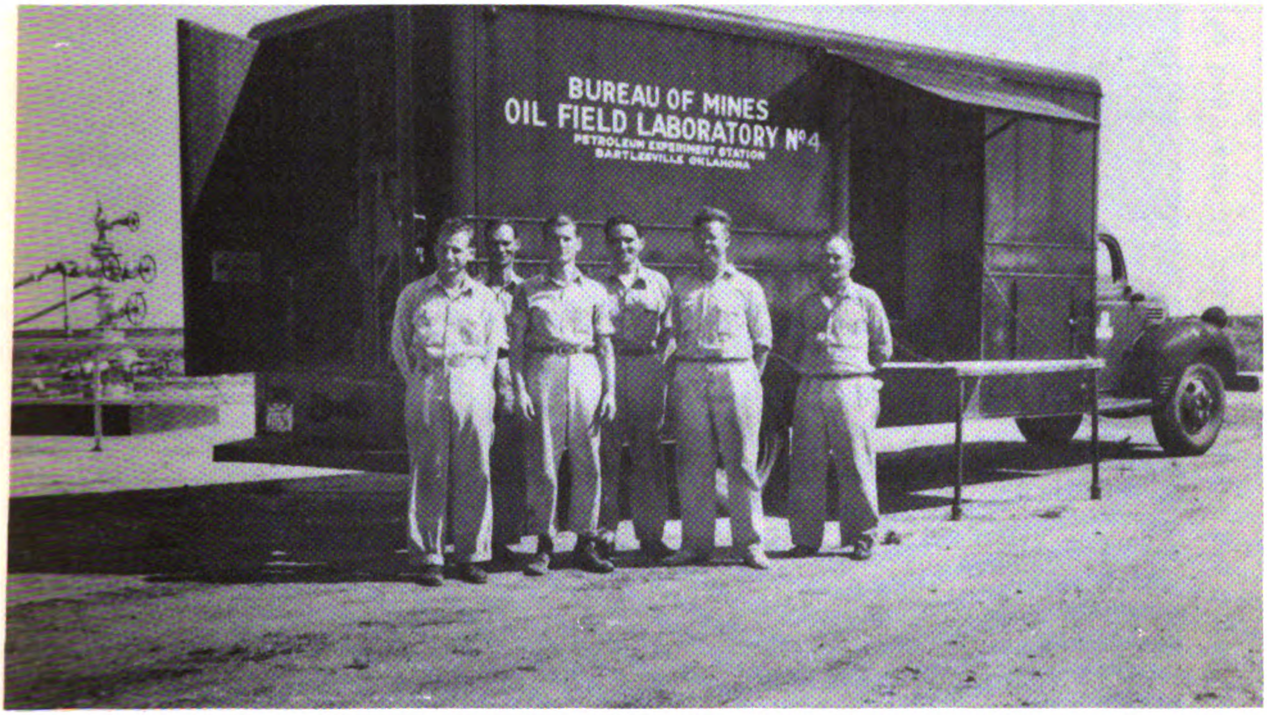

Figure 1. - Field party of Bureau of Mines engineers and portable laboratory in which the properties of fluids from gas-condensate wells are analyzed. The testing equipment is connected to the wellhead fittings with flexible, high-pressure tubing.

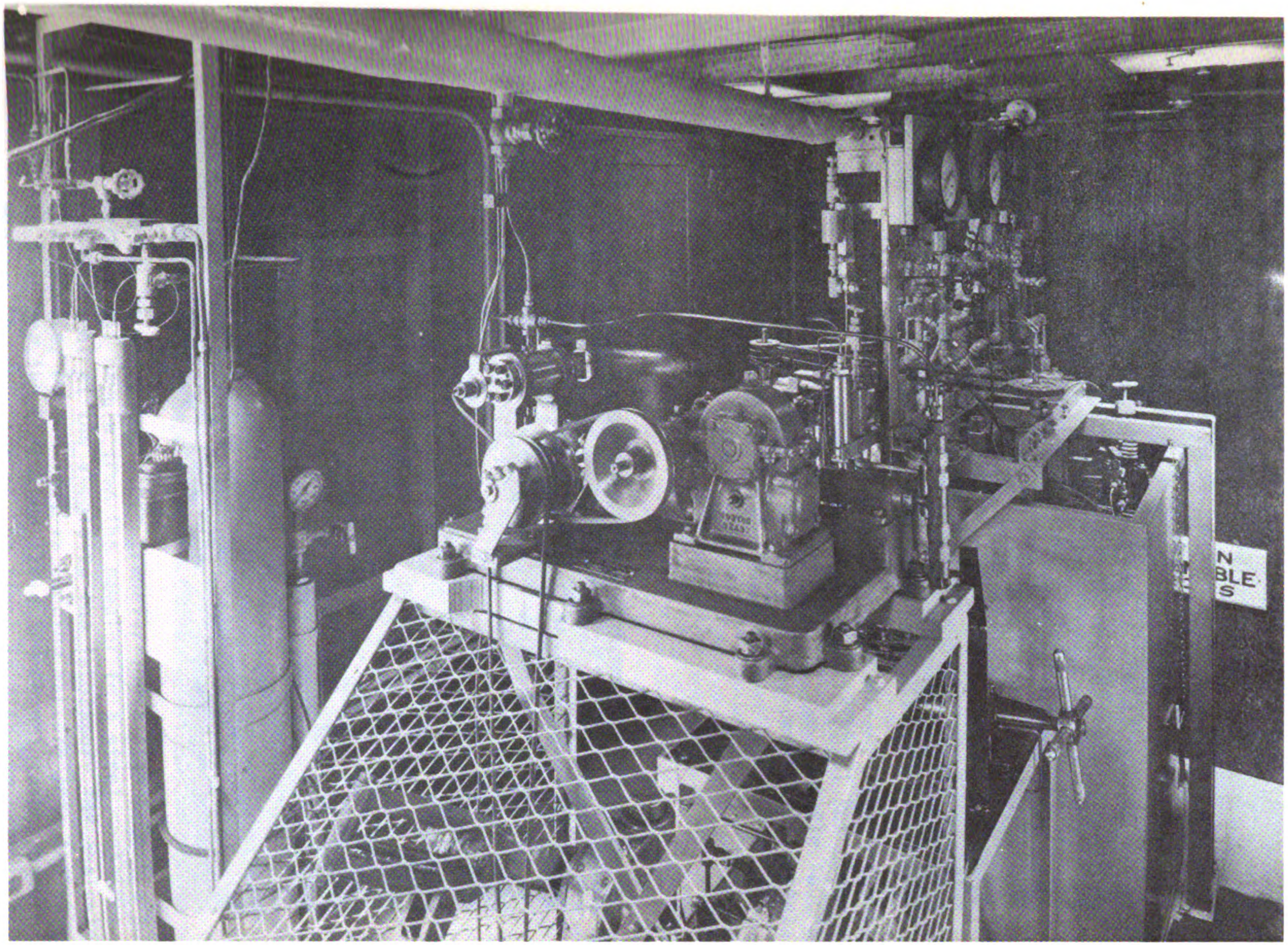

Figure 2. - View of high-pressure pumps and accumulator bath in rear end of portable laboratory.

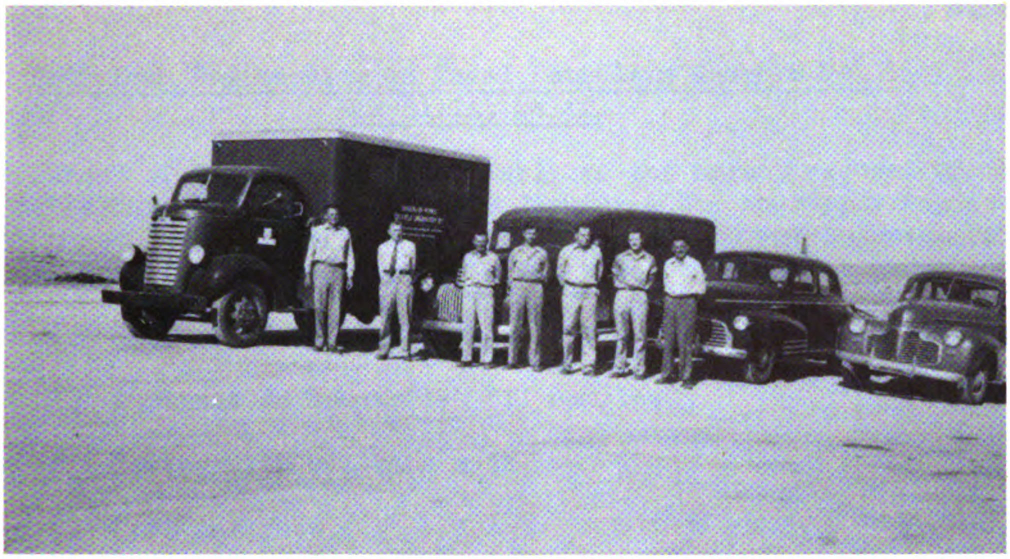

Figure 3. - Petroleum engineers of the Bureau of Mines, with automotive equipment, assigned to field studies in Naval Petroleum Reserve No. 1, Elk Hills, Calif. The two portable laboratories brought most of the testing equipment half across the continent on this war assignment.

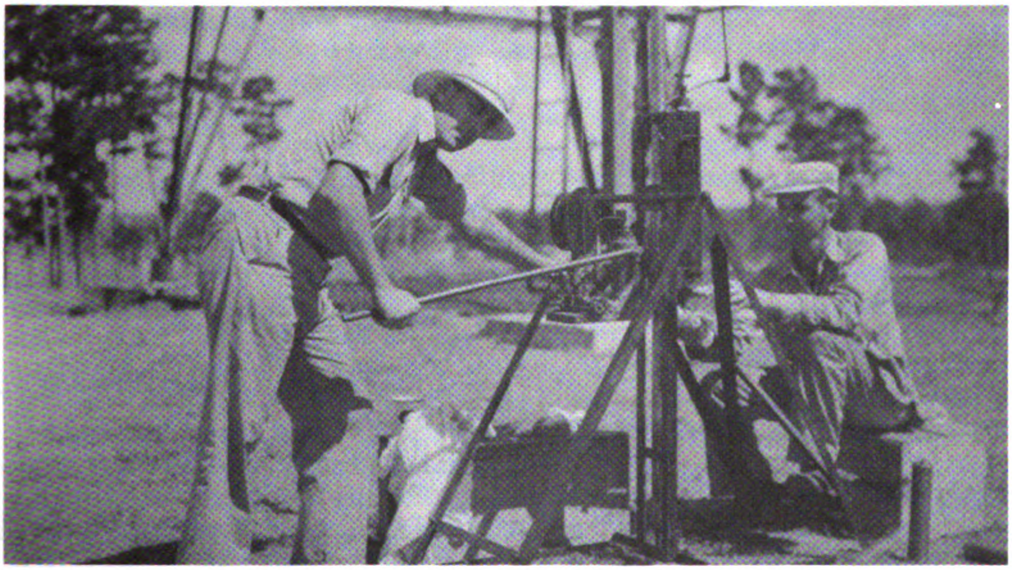

Figure 4. - Bureau of Mines engineers transferring a high-pressure subsurface oil sample from the sampler to a steel container for shipment of the sample to the laboratory for analysis. The operator on the left is pumping mercury into the sampler to displace the contained fluid and to maintain pressure whereas the operator on the right is allowing mercury to flow from the mercury-filled shipping container so as to admit the sample.

Petroleum Engineering in Naval Petroleum Reserve No. 1, Elk Hills, Calif.

The Bureau of Mines responded quickly to the urgent request of the United States Navy, made officially in January 1945, to supply engineering information required to carry out its development program in Naval Petroleum Reserve No. 1. Four general types of work were performed:

1. Subsurface measurements of pressures and temperatures.
2. Analyses of subsurface oil samples.
3. Coring with oil-base muds.
4. Core analyses.

By suspending other work in progress at Bartlesville, Okla., and San Francisco, Calif., a field party composed of engineers from both field headquarters was organized in the Elk Hills field, so that work started on these problems during the latter part of February. Much of the equipment had to be transported by truck from Bartlesville. Figure 3 shows the Bureau of Mines group assigned to the work, some of whom were still in the Elk Hills field at the end of the fiscal year.

The data were supplied directly to the Navy representatives and the engineering committee of the Unit Operators. The value and importance of the results of this work in the war program is evidenced by expressions from the Navy Department for this outstanding service.

Subsurface Measurements

Pressure surveys were conducted in 57 wells, most of which were pumping wells. In these, the instruments were lowered to the bottom of the well through the annular space between the tubing and the casing. Pressures and temperatures also were obtained on three deep-flowing wells in which the instruments were run through the tubing by the conventional method.

Analyses of Subsurface Oil Samples

A program of sampling and analyzing the oil from at least five zones in the Elk Hills field was started during the year. The results of the analyses on two subsurface samples, including the quantity of gas in solution, by both differential and flash methods, shrinkage of oil resulting from liberation of gas from the oil, and other physical characteristics of the reservoir oils were reported to the Navy and the Unit Operators. Three other samples were obtained and were being analyzed in the field laboratory at the end of the fiscal year. Figure 4 shows the method of transferring a sample of reservoir fluid from the subsurface instrument to a high-pressure container for shipment to the laboratory.

Core Analyses

As the urgency of the assignment did not permit purchasing new equipment for this work, most of it was taken from the Bartlesville laboratory. At the conclusion of the 3-months' testing period, this equipment was transferred to the laboratory of the San Francisco Petroleum Field Office, supplying a long-felt need for a "set-up" of this kind to be used in future work on reservoir rocks by personnel of that field headquarters.

The oil-bearing sandstones in the Elk Hills field are so friable that it was necessary to construct some special equipment to augment that brought to the field. Part of the temporary core laboratory is shown in figure 5. The tests included determinations of porosity, permeability, oil and water content, and the chloride content of the contained water. During the operation of the core laboratory in the field, the engineers tested 617 samples from 140 cores taken from 20 wells. Some cores were taken with oil-base muds, whereas others were from wells cored with water-base muds. The results of tests on cores from each well were plotted in the form of a "core-graph," so that the results could be visualized and interpreted readily.

Engineering Work in Other Types of Fields

West Edmond Field

Three studies were carried on in the West Edmond, Okla., field in cooperation with the State of Oklahoma. Oil samples were obtained from two wells producing from the Bois d'Arc formation of the Hunton limestone and analyzed to determine the quantity of gas in solution by both the differential and flash liberation methods and the shrinkage and other physical properties of the reservoir oil. The results of these studies have been published.[4] During the field work it was observed that the earth temperatures varied from one part of the field to another, and to explore this condition the Bureau obtained pressure and temperature gradients in 23 wells. The data were forwarded to the West Edmond Field Engineering Committee and to the Corporation Commission of Oklahoma.

Operators used conventional methods of coring during early development of the Bois d'Arc section of the West Edmond field. The percentage of recovery of core samples from certain portions of the oil reservoir was very low, and few data for reserve estimates from core analyses were available. In conference with the Engineering Committee, operators, and engineers of the Corporation Commission, Bureau of Mines engineers suggested that diamond bits and a different technique of coring be tried instead of using conventional-type cone or hard-rock bits. This suggestion met with favorable response, and the Bureau engineers were instrumental in obtaining the services of a company competent in the art of diamond drilling for operations in the field.

4/ Cook, Alton B., Dewees, E. J., and Harris, H. M., Bureau of Mines Analyses of Subsurface Oil Samples, West Edmond field, Okla.: Petrol. Eng., vol. 16, No. 8, 1945, pp. 85-92, 7 tables, and 5 figs.

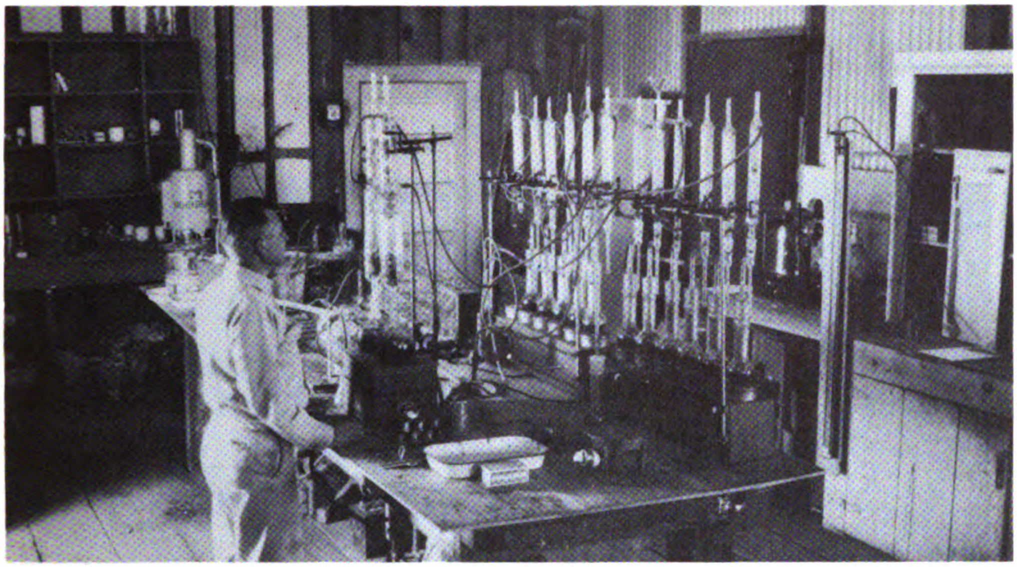

Figure 5. - Field laboratory for core analysis, U. S. Naval Petroleum Reserve No. 1.

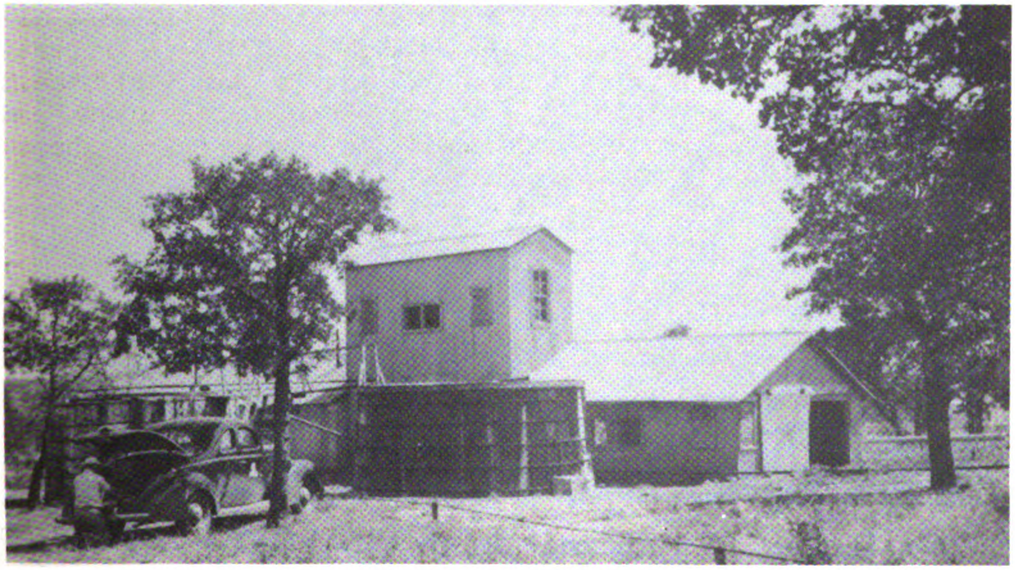

Figure 7. - Typical north Texas water-treating plant. The engineer (left foreground) is making chemical tests on a sample of treated water to ascertain its suitability for injection into the oil-producing formation.

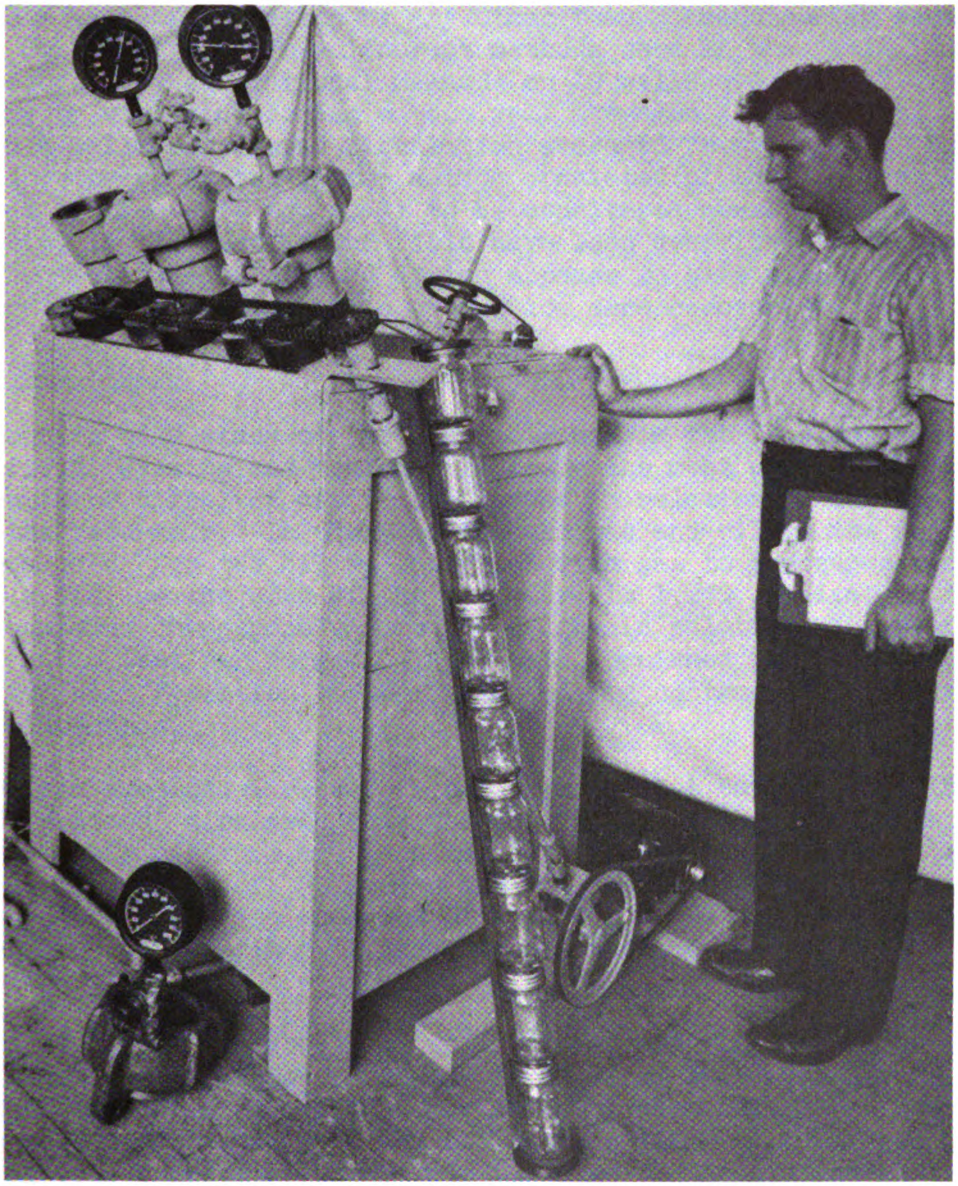

Figure 6. - Cells used in the laboratory investigation of corrosion under high pressures.

On the first well cored with diamonds, 57 feet of the formation was cored and 48 feet 2 inches, or 84.5 percent, was recovered. In the second well the entire section of the Hunton limestone of 342 feet was cored, and 332 feet, or 96.79 percent, of the formation was recovered. The upper part of the Hunton limestone in the West Edmond field is very badly fractured, with secondary deposition of glauconite in the fractured zones, and to recover cores of this type of formation by any other than diamond coring seemed impossible. Core recoveries by different methods used in the field indicates that the recovery by conventional methods on 10 wells averaged 42.8 percent, the recovery by wire-line coring on one well averaged 31.3 percent, and the recovery on 4 wells by reverse circulation averaged 78.8 percent. However, most of the recovery by the latter method consisted of small pieces or cuttings. Most of them were too small to be considered cores. The details of diamond coring in the West Edmond field have been described in the technical press.[5] The technique of diamond coring appears to have wide application to fields where the use of steel bits causes low core recoveries.

Rocky Mountain Fields

The results of a study of the reservoir oil in the Tensleep sandstone, Elk Basin field, Wyoming and Montana, indicate the most unusual condition that the ratio of dissolved gas to oil varies in relation to structural position in the reservoir. In other words, the gas and oil in the reservoir are not equalized, for the oil is saturated with gas to pressures ranging from 540 p.s.i.a. on the edge of the structure to 1,250 p.s.i.a. on the crest and contains corresponding amounts of gas in solution ranging from 130 to 480 cubic feet per barrel. These data furnished part of the engineering basis for unit operation of the field and for contemplated reservoir pressure maintenance.

Subsurface samples of reservoir oil from the Cut Bank sand in the Cut Bank field, Montana, disclosed that the virgin oil is saturated with gas to existing reservoir pressure and provided data to indicate that at the original reservoir pressure of 750 pounds the oil contained 275 cubic feet of gas per barrel of oil. The analyses of oil from six wells have formed part of the basis for an experimental pressure-maintenance program in one section of the field.

In the new field at Gebo, Wyo., oil is produced from the Embar and Tensleep formations. Samples of reservoir oil from three wells were obtained and analyzed, and the flowing characteristics of the wells were determined, furnishing data to indicate that the oil in this field will be produced as a result of an active drive of water from the edge of the oil reservoir.

Corrosion Studies

During the year a study was begun of the problem of internal corrosion in the tubing and wellhead fittings of high-pressure, high-temperature gas-condensate wells. Companies operating in fields of the gas-condensate type observed that wellhead fittings and tubing in some of the wells had become very badly corroded. The internal corrosion frequently was so severe that the equipment appeared to be on the point of failure. The problem is of extreme importance to the industry, as failure of the equipment at high-pressure wells would be serious. Wild wells not only are dangerous to persons working nearby but are wasteful of irreplaceable natural resources. Fields in which severe corrosion has been noted are, for the most part, in east Texas, north Louisiana, and the Gulf Coastal regions of Texas and Louisiana.

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[5] Fagin, Marshall, Diamond Bit Cores, Hunton Lime Pay, in West Edmond Field, Okla: Petrol. Engr., vol. 16, No. 8, 1945, p. 237.

Substantial progress has been made in the investigation of internal corrosion and of means of inhibiting or decreasing the rates of corrosion. Laboratory tests have indicated that sodium chromate will inhibit the corrosive action of dissolved carbon dioxide, phenol, and organic acids (formic, acetic, proprionic, butyric, and valeric acid), which may be present in the condensed water vapors produced from gas-condensate wells. Any one or a combination of two or more of these substances may be responsible for the very severe corrosion of well fittings. It appears that erosion as well as corrosion may be a factor contributing to the destruction of the fittings. Studies of these conditions are in progress. Figure 6 shows the constant-temperature bath and pressure cells in which long-time corrosion tests are being made. A rack of glass jars containing metal coupons is placed in each of the cells. One of these racks is shown leaning against the bath.

Alterations to Portable Laboratory

The portable laboratory, which was designed early in the war to study the properties of the fluids in gas-condensate reservoirs and the dew points of the various gases, was rearranged to permit making field studies of corrosion in high-pressure high-temperature wells. The sample of fluid withdrawn from a flowing well by means of a sampling nozzle is representative of the fluid as to hydrocarbons, but it does not contain the proper proportion of water. A high-pressure water pump, mounted on top of the expanded metal guard (see fig. 2), was installed in the portable laboratory to inject water into the flow stream from the sampling nozzle at pressures up to 7,200 p.s.i. and at rates up to 0.025 gallon per hour. A high-pressure window made from stainless steel and containing two glass Poulter-type windows was constructed and installed to measure and indicate the rate of flow from the high-pressure water pump. A new 4-cylinder, water-cooled engine having 70 percent more power than the single-cylinder, air-cooled, gasoline engine previously used was installed in the truck to improve the operation of generators, vacuum pumps, and stirrers.

SECONDARY RECOVERY

Before the United States entered the war, it was known that modern warfare would require unprecedented quantities of petroleum products, but the thought prevailed that "shut-in" or prorated production would be adequate to meet military and civilian demands. As the war progrrssed, however, it became evident that the "shut-in" production was not enough, and in 1943 production exceeded additions to new reserves from all sources. As the number of new discoveries decreased, this country looked anew at its production of petroleum from settled fields, realizing that the protection of petroleum reserves in marginal and stripper areas had become increasingly important.

The Bureau of Mines has been active in secondary recovery studies since 1917, and in recent years it has stressed this work to increase the production of crude petroleum and, which is more important, to prevent the premature abandonment of wells in "stripper" and marginal areas.

Methods of Increasing The Recovery of Oil

To stimulate interest in the application of secondary-recovery methods in the Mid-Continent area, with consequent reduction of premature abandonments of producing wells, the Bureau published two reports giving in detail the results of water-flooding operations in Kansas[6] and Illinois,[7] while a third, relating to north Texas,[8] is being prepared.

Water-flooding in Kansas began on a planned basis in 1935 with the passage of a State law authorizing this method of petroleum recovery. By 1936, three initial projects had demonstrated the practicability of the method, and by November 1942, the practice was being followed in 13 counties. Fifty-two water-flooding projects have been undertaken on 2,612 acres in Kansas, with recovery of approximately 4,200,000 barrels of oil to November 1942. Although a small part of the oil recovered by water-flooding would have been gained by primary methods, most of the water-flooding operations in Kansas were on properties that had almost reached their economic limit of primary production. The report by Grandone[9] describes each of the water-flooding projects, discusses the source and treatment of injection water, and gives information on well spacing, well-completion methods, and well-shooting practice.

Increased interest in the possibilities of water-flooding in Illinois fields came about in recent years when chance flooding of oil-bearing sands through leaky well casings or other accidental means resulted in unexpected increases in the rate of oil production in the older fields in the southeastern part of the State. As of July 1, 1943, some 15 experimental flooding projects were in operation, and operators were making preparations to begin additional projects as soon as the economic factors were better established. Many of the shallow fields in southeastern Illinois appear to be well-suited to water flooding; however, a major problem in many fields is an adequate supply of water. Report of Investigations 3778 discusses each of the 15 water-flooding projects in operation on July 1, 1943 and gives injection and production records, maps of the properties, core analyses, and other pertinent data.

The report in preparation on water-flooding practices in north Texas follows the pattern established in the reports relating to water flooding in Kansas and Illinois, wherein each project is described by means of text, maps, and tabular data. Bureau of Mines engineers visited each plant and made many field tests on the water used for flooding. Figure 7 shows such tests being made at a typical north Texas water-flooding plant by means of a portable chemical-test unit. To January 1, 1945, there were 38 water-flooding projects in north Texas covering 2,243 acres. These projects had resulted in a recovery of 1,144,553 barrels of oil or 510 barrels of oil per acre.

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[6] Grandone, Peter, History of Water Flooding of Oil Sands in Kansas: Bureau of Mines Rept. of Investigations 3761, 1944, 146 pp.

[7] Taliaferro, D. B., Keithly, C. M., and Jennings, Thomas, Water Flooding of Oil Sands in Illinois: Bureau of Mines Rept. of Investigations 3778, 1944, 23 pp.

[8] Grandone, Peter, Jessup, D. A., and Taliaferro, D. B., History of Water Flooding of Oil Sands in North Texas: In manuscript.

[9] See footnote 6.

Although water flooding has been successful in sandstone reservoirs in many areas, this practice presents additional problems when applied to limestone reservoirs. Report of Investigations 3792[10] describes the first systematic water-flooding project ever tried in an Illinois oil-producing limestone reservoir. Describing the project on a 13,000-acre tract in the McClosky limestone of the Clay City field, the report shows that an increased production of 87,000 barrels of oil was obtained by injecting 1,900,000 barrels of raw river water into three old wells along the edge of the field. Much of the oil might not have been produced by continued use of primary extractive methods.

A survey was made of air-gas injection operations in Illinois to acquaint the operators with the effectiveness of this secondary recovery method throughout the State. The results of this survey[11] show that the first Illinois gas-injection project was started about 1921, and since then the method has been extended to more than 32,000 acres. In July 1943, 99 such projects were in operation in the State, the Robinson field in Crawford County offering the most favorable opportunities for profitable development in the older fields. The quantity of oil gained from these fields by projects that have been operating for 9 or 10 years is not spectacular when compared with results obtained by successful water-flooding operations. However, development costs for gas-injection projects in the older fields of Illinois have been so low that profitable operation has been assured over a longer period of time than the life-expectancy of an average water-flooding project. The report discusses in detail four of the 99 projects in Illinois and provides factual information for guidance of other operators contemplating similar secondary recovery projects.

A detailed engineering study of the Delaware-Childers field in Nowata County, Okla., is being made to evaluate the results of air-gas injection operations that have been in progress in that area for many years. Data being assembled include core analyses, drillers logs, lease maps, and records of the volumes of oil produced and gas injected.

Because of the urgent need for greatly increased rates of oil production during World War II, a report[12] was prepared for the guidance of operators of stripper wells in the Appalachian region. The report dealt with applications of engineering principles that could be applied quickly to increase production under wartime shortages of manpower and equipment. Stimulative oil-production methods were described that could be used to increase production rates temporarily without hazard to probable ultimate recovery. Later, more intensive and better-engineered projects can be substituted when restrictions on manpower and equipment are eased or when economic conditions become more favorable. A large portion of the report was devoted to safety in the compression of air and air-gas mixtures, because air is the principal injection medium when natural gas is scarce and expensive.

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[10] Riggs, C. H., Water Flooding the McClosky Limestone in Clay City Oil Field: Bureau of Mines Rept. of Investigations 3792, 1945, 20 pp.

[11] Keithly, C. M., and Jennings, Thomas, Air and Gas Injection in the Oil Fields of Illinois: Bureau of Mines Rept. of Investigations 3783, 1944, 60 pp.

[12] Taylor, Sam S., Wartime Application of Air-Gas Injection and Oil-Well Reconditioning in the Appalachian Region: Bureau of Mines Rept. of Investigations 3777, 1944, 38 pp.

Interest in mining petroleum from partly depleted oil fields has increased during the past several years. Preceded by pilot "mining" operations in Texas and Ohio, an experimental project (although of commercial size) utilizing a technique of drilling horizontal holes into an oil sand from a vertical shaft was started near Franklin, Pa., in 1942. A report[13] resulted from a study made by Bureau engineers and others during the development of the project. The report is an engineering account of the sinking and lining of the shaft, selection and installation of drilling and auxiliary equipment, and the horizontal core-drilling technique. The report contains a megascopic description of consecutive core sections representing perhaps the longest core ever drilled in an oil sand. The core was drilled horizontally 2,334 feet in one direction and 2,255 feet in the opposite direction from the 27-foot-diameter chamber at the bottom of the shaft.

A report is in preparation that will present an engineering analysis of the advantages derived from various methods used in the Appalachian region to clean out oil wells to increase production rates. In partly depleted oil fields where the production rates of wells have declined because the oil-moving energy in the reservoir has reached a low ebb, it is especially important that wells be kept clean; for obstruction to oil flow into the wells, caused by accumulations of cavings and waxy or salty deposits on the sand face, may falsely indicate natural declines of the oil-production rates and sometimes lead to premature abandonment of good wells.

Mid-Continent oil producers are using old pipe lined with cement material that resist corrosive fluids, thus effecting substantial savings of steel. A report[14] describes the method of applying the cement lining, the cost of the operation, and the effectiveness of the application. Much of the salvaged pipe is being used for water-flooding in secondary recovery projects in northeastern Oklahoma and southeastern Kansas, for brine-disposal systems in western Kansas and east Texas, and for oil-gathering lines throughout the Mid-Continent area, where the fluids handled are particularly corrosive to steel. Frequently the salvaged pipe serves equally well as cement-lined new pipe.

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[13] Elder, C. W., Jr., Horizontal Drilling for Oil in Pennsylvania, A Preliminary Report: Bureau of Mines Rept. of Investigations 3779, 1944, 68 pp., 14 figs.

[14] Grandone, Peter, Reclaiming Used Pipe for Oil-Field Operations with Cement Lining: Bureau of Mines Inf. Circ. 7314, 1945, 10 pp.

The cost of cement lining ranges from 7-1/2 cents per foot for 1-1/2-inch pipe to 25 cents per foot for 6- to 7-inch pipe.

The value of the Bureau's secondary recovery studies to the oil industry is evidenced by the following resolution adopted by the Interstate Oil Compact Commission:[15]

Resolution

> The Commission calls attention to two reports relating to water-flooding recently published by the United States Bureau of Mines.
>
> The first report, "History of Water Flooding of Oil Sands in Kansas" (R. I. 3761), was published under a cooperative agreement between the Bureau of Mines, the Kansas State Board of Health, and the Kansas State Corporation Commission. This comprehensive report contains detailed operating information and production data on 52 projects from which more than 4 million barrels of oil have been recovered since the first water flood was started in 1936.
>
> The second report, "Water Flooding of Oil Sands in Illinois" (R. I. 3778), contains the initial details of several projects. Systematic water flooding in Illinois is a recent development; however, accidental floods have indicated that many fields in this State will respond to this type of secondary recovery.
>
> The Interstate Oil Compact Commission commends these excellent reports, as the application of secondary-recovery method is a most valuable conservation measure, in that it prevents premature abandonment of producing properties, and strongly recommends that this type of work by the Bureau of Mines in cooperation with oil-producing States and the industry be continued and expanded as rapidly as conditions permit, so as to make available to oil operators technical information that will stimulate secondary-recovery operations.

Recovery of Wax from Crude Petroleum Wastes

Intensive study and experimentation have resulted in numerous improvements in the operation of the pilot plant near El Dorado, Kans., designed for the recovery of microcrystalline wax distillate from oil-field waste emulsions. A cleaner distillate with lower salt content has been obtained by the addition of a conditioning tank for homogenizing the complex emulsion before it is chemically treated by the addition of an insulated tank for settling the water and dirt before the separated oil is dehydrated, and by improvements made in the chemical treating procedure to accelerate the "break" of the emulsion. As much of the waste on which the plant is operating is in the form of solid cake that floats on top of a lower layer of liquid, a power-operated drag has been installed to help move the solid waxy material into the plant.

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[15] Interstate Oil Compact Quarterly Bull., vol. III, No. 3, Oct. 1944, pp. 107-8.

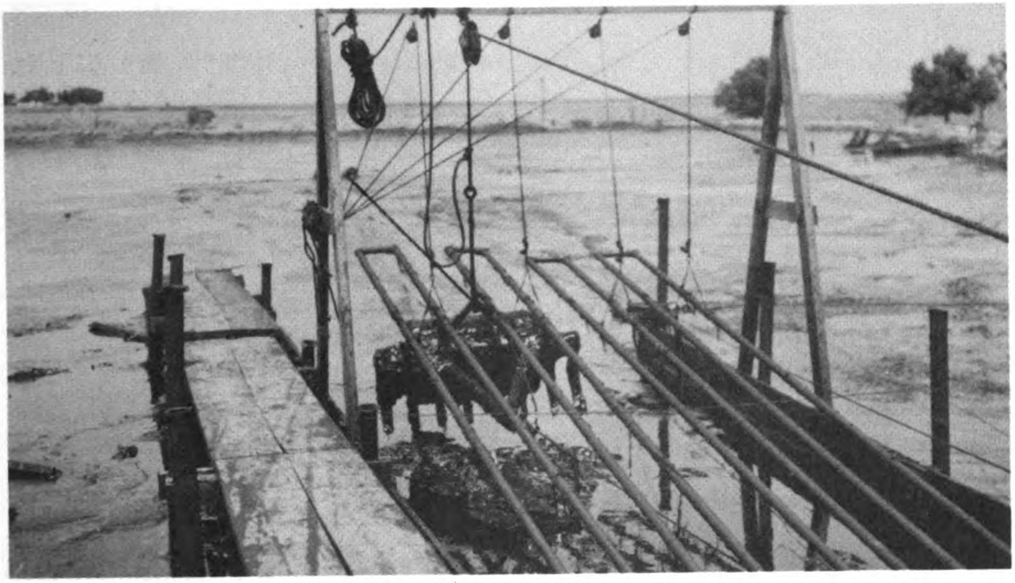


Figure 8. - Sharp-toothed drag for bringing wax emulsion to pilot plant and steam coils for liquefying raw material. Drag and coils in elevated position.

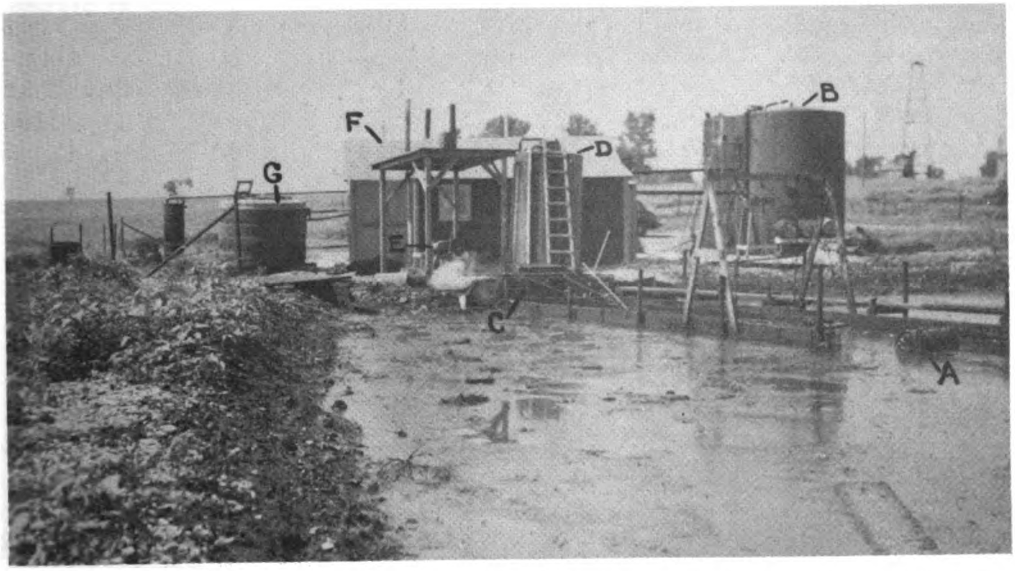


Figure 9. - General view of west side of pilot plant showing (a) drag entering slip, (b) storage tanks, (c) head gate to flume, (d) conditioning tank for crude wax emulsion, (e) gasoline winch, (f) laboratory and other buildings, and (g) insulated settling tank.

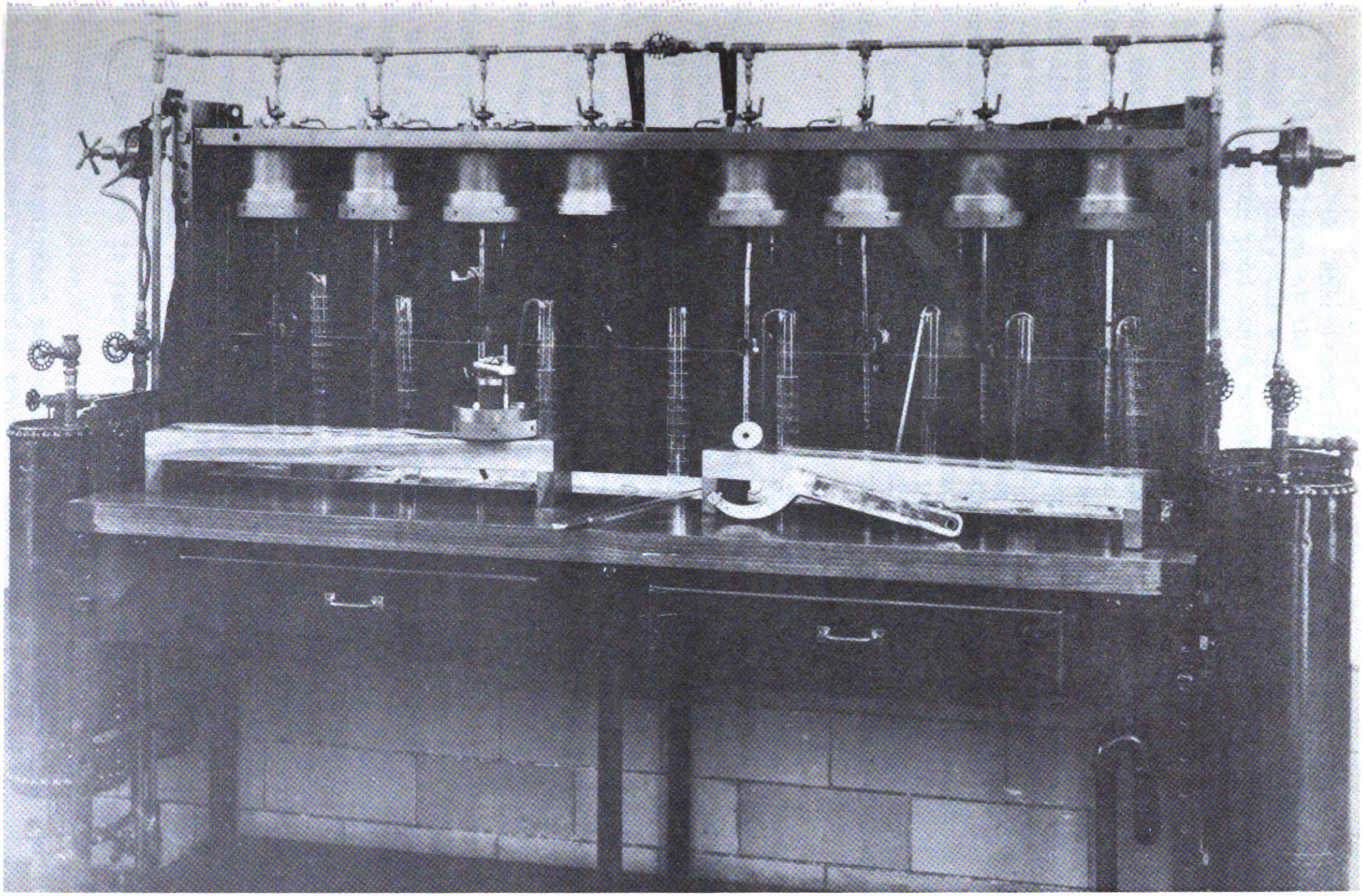
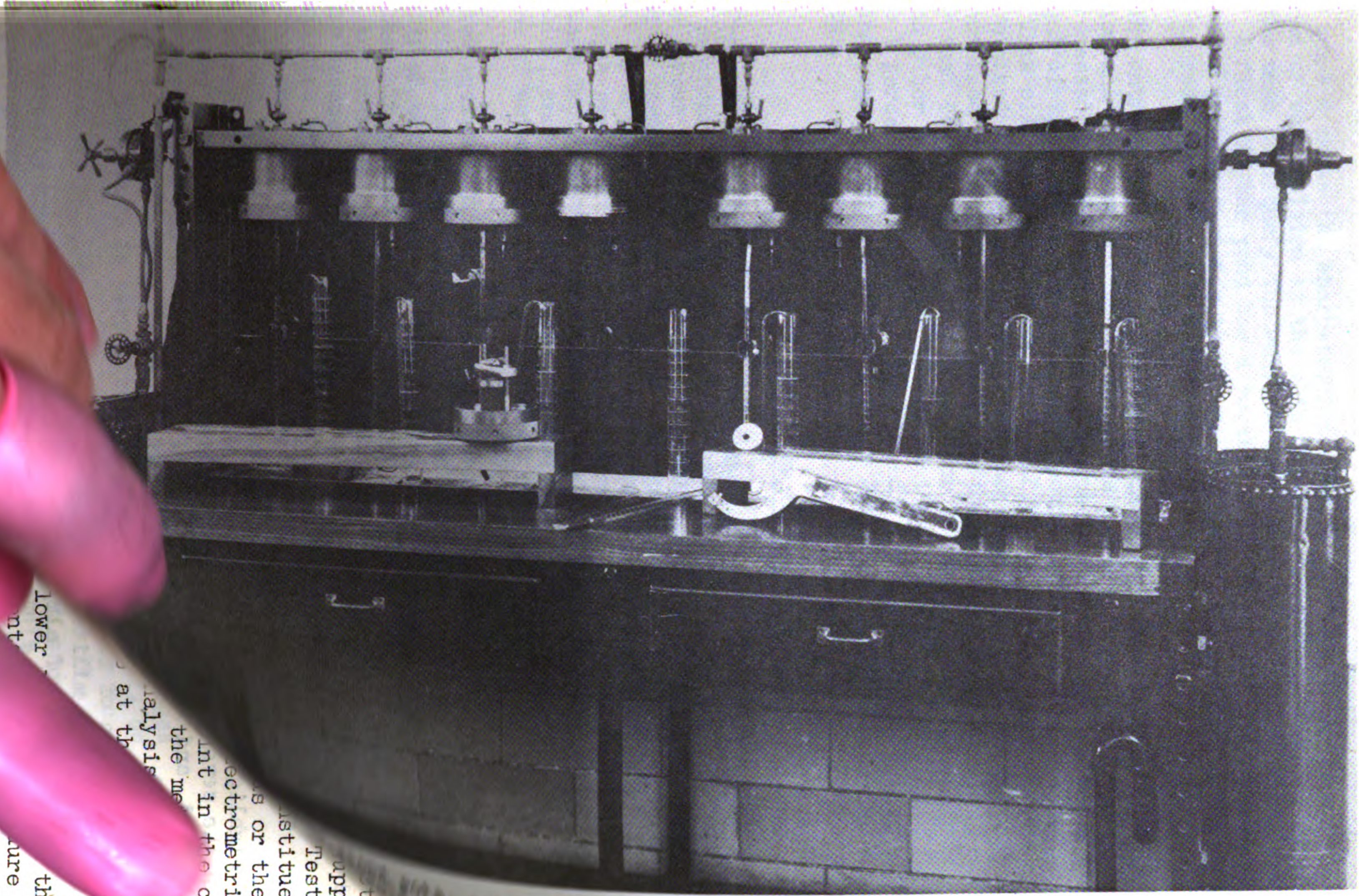


Figure 10. - Battery of flood pots, core and water laboratory, Petroleum Experiment Station, Bartlesville, Okla. A manifold system connecting the flood pots and their contained cores with four pressure tanks, holding different flooding agents, adds to the flexibility of experimentation.



core and water laboratory, Petroleum Experiment Station, Bartlesville, connecting the flood pots and their contained cores with four different flooding agents, adds to the flexibility of experimentation.

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Figure 8 shows the sharp-toothed drag just after it has been lifted from the load of wax emulsion at the slip and the steam coils that are lowered into the mass to liquefy the wax. A small double-drum power winch works the drag. A float in the pond has a movable arc with a 150-foot radius, which provides a working area for the drag. Figure 9 is a general view of the plant as seen from the east bank of the pit.

The untreated waste oil now being charged to the plant is 55 percent emulsion and dirt containing 3,600 pounds of salt per 1,000 barrels, whereas the processed oil obtained on recent tests contained only 0.8 percent emulsion and dirt, no water, and only 12.3 pounds of salt per 1,000 barrels of oil. This oil had a gravity of 31.2° A.P.I., a melting point of 130° F., and contained 18 percent microcrystalline wax. Ninety-two percent of the oil contained in the stock charged into the plant was recovered. The refinery that is taking the treated oil for the manufacture of microcrystalline wax and other products limits the solid impurities and water content of the oil to 1 percent and the salt to 20 pounds per 1,000 barrels of oil. The treating capacity of the pilot plant is seven barrels of the charging stock per hour.

Core and Water Laboratory

Production engineering, whether applied to fields of primary extraction or to secondary recovery, demands accurate information on the characteristics of the porous reservoir rocks and the composition of oil-field waters contained in them and of surface and near-surface waters used in flooding operations. As a part of the Bureau's program of research and oil-extraction methods, a small but well-equipped laboratory has been developed at the Petroleum Experiment Station, Bartlesville, Okla., in which porosity, permeability, and other determinations are made on typical core specimens, and samples of water are analyzed for their mineral content and reactive properties.

New equipment installed in the laboratory includes a battery of flood pots, which is shown in figure 10. These pots are used to determine the quantity of oil that can be recovered from an oil-bearing sandstone by water flooding. They also are used to compare the efficiency of various flooding media and methods. An electric titrimeter, which had given unsatisfactory results because of variations in the voltage of the local electric supply, was equipped by the manufacturer with a voltage stabilizing unit. Tests then were made to devise procedures whereby the usual mineral constituents of oil-field brines might be determined by electrometric methods or the end point of reactions in standard methods might be determined electrometrically. Preliminary investigations indicate that the equivalence point in the chloride determination can be determined by this method; that the methyl-orange end point on the carbonate, bicarbonate, and hydroxyl analysis can be determined; but that there is very little measurable change at the phenolphthalein end point.

The porosity equipment was modified to use lower pressures, and the deadweight gage previously used for pressure measurements of the procedure was replaced by a 100-inch, well-type, mercury manometer. This increased the accuracy and speed of this determination. A battery of eight electrically heated retorts for the determination of oil and water content of cores is being installed in the laboratory. The core sample is charged into a brass tube that may be placed in the retort or removed from it without disturbing any connections. With this construction, a spent sample may be removed from the retort and another sample (in another brass tube) may be charged without the necessity of cooling the retort. After the retort is hot, the time required for determination is reduced to about 20 minutes. The extraction method, which has been used exclusively in the past, is more accurate but requires several hours for each determination.

Standard mineral analyses were made on 57 water samples during the year, and 61 core samples were tested. In addition, numerous special tests, such as determinations of chlorides and dirt in refined wax, viscosity, surface and interfacial tension of crude oil, and nitrate tests on boiler feed water, were made. Some preliminary work was done on friable core specimens from wells in Naval Petroleum Reserve No. 1, which served as an experience factor in making a large number of these analyses in a field laboratory in Elk Hills, Calif., as described in another section of this report.

PETROLEUM CHEMISTRY AND REFINING

Petroleum chemistry and refining research conducted on a coordinated plan at the Petroleum Experiment Station, Bartlesville, Okla., and the Petroleum and Oil Shale Experiment Station, Laramie, Wyo., was oriented toward the optimum utilization of crude oils in the manufacture of aviation fuels for spark-ignition and jet-propulsion engines. The work involves intensive studies of superfractionation, hydrocarbon analysis, and the engine testing of fuels. The effects of sulfur compounds in the crude oils and in the fuels made from them were given particular attention.

Post-war developments will demand greater knowledge of the composition of petroleum, and of the characteristics of improved petroleum products. The studies of aviation fuel form the groundwork for research programs designed to obtain accurate data on the hydrocarbon composition and the properties of distillates from all types of crude oil. Early recognition of the necessity for increased use of sulfur-bearing oils in the post-war economy has made possible a comprehensive program of research on sulfur in petroleum that is designed to provide data helpful in refining such crude oils.

Aviation Fuels:Spark Ignition

The highlights of accomplishments during the last fiscal year are portrayed in the several reports that were completed. With few exceptions, they are restricted, and some represent special work not yet approved even for restricted release.

The preparation of finished aviation gasoline of grade 100/130, which is currently used in all military operations, was continued for the third year, with studies of blends of alkylate and cumene with aviation-base stocks prepared from both East Texas, Tex., and Elk Basin, Wyo., crude oils. In addition to showing the possibilities of utilizing these naphthas in making aviation-gasoline blends, hydrocarbon analyses of the naphthas were included.

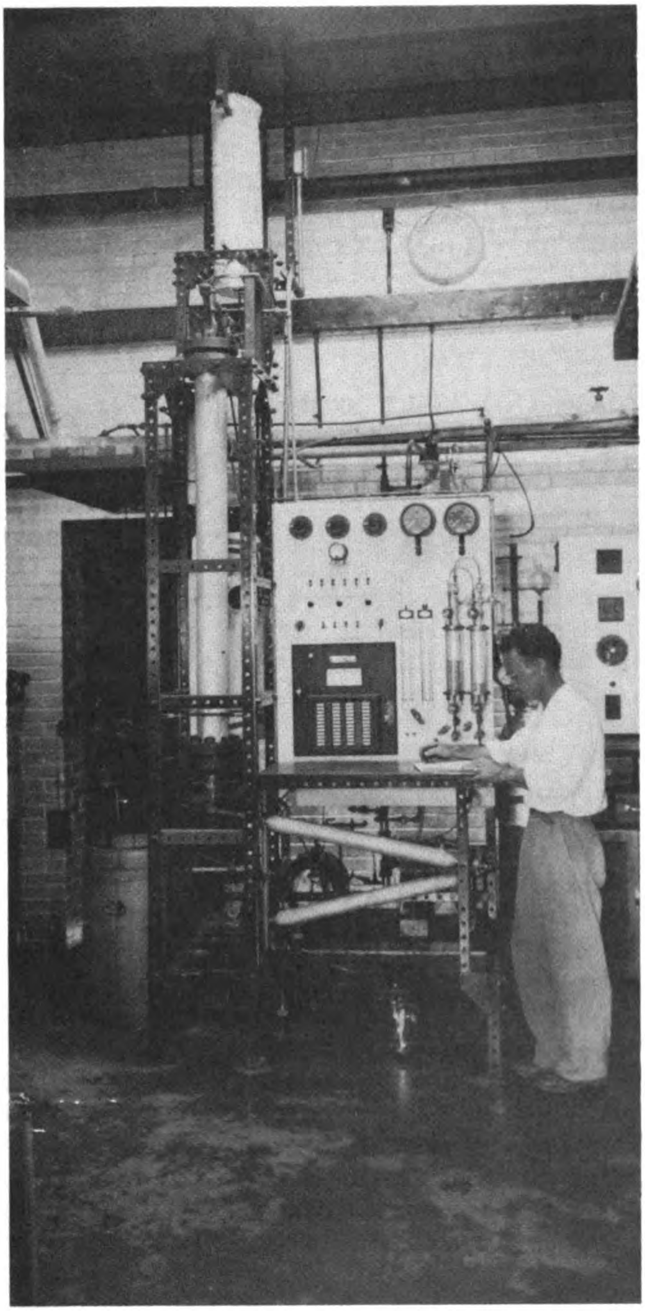

Figure 11. - Typical experimental equipment at the Petroleum Experiment Station, Bartlesville, Okla., used for catalytic desulfurization studies of naphthas, gas oil, and crude oils. The instruments on the panel board enable the operator to follow the reaction within the unit. An electromic temperature recorder provides for as many as 36 readings within 10 minutes.

These data have immediate and postwar value as the composition of gasoline is being increasingly emphasized. The research on Elk Basin naphtha also included studies showing the effect of desulfurization. By catalytic desulfurization with bauxite, the sulfur content of this naphtha was reduced so that an appreciable part was suitable for blending into aviation gasoline, whereas, without desulfurization the naphtha could not be used in that way. The use of desulfurization, of course, would apply to the preparation of straight-run motor gasoline with attendant greater yields and higher octane values. Figure 11 is a photograph of the experimental equipment used in desulfurization studies of naphthas.

One of the desiderata in research on fuels is the calculation of octane numbers from hydrocarbon analysis or the development of a rating scale that will facilitate such procedure. In order to do this, it is necessary to know the "blending octane numbers" of the various individual hydrocarbons. Cyclohexane and 2-methylpentane occur in many naphthas, but their "blending octane numbers" are not well-established. These two hydrocarbons were studied, and some of the data obtained have been accepted by the American Petroleum Institute (project 45) for inclusion in the annual tables giving the best data on engine response of pure hydrocarbons. The hydrocarbons used in this work were purified at the Laramie, Wyo., Petroleum and Oil Shale Experiment Station.

Aviation Fuels:Jet-Propulsion

Early in the spring of 1945 the increased use of jet-propulsion engines forecast a possible shortage of suitable straight-run fuel for such engines. The Bureau was requested by the National Advisory Committee for Aeronautics, in conjunction with the Petroleum Administration for War, the Army, and the Navy, to make an extensive study of 10 different crude oils covering the principal types of petroleum. These 10 crude oils were distilled in a manner analogous to that used in Bureau of Mines Hempel distillations, and the physical and chemical properties and the composition of the several fractions and blends thereof were determined. From this work it was hoped that a correlation might be developed whereby several thousand Hempel analyses that the Bureau has available could be evaluated. This would enable selection of the fields producing petroleum most likely to yield suitable jet-propulsion fuels. This work was approximately 75 percent complete on July 1, 1945, and a progress report of 40 pages was prepared summarizing the work to that date. This material has been made available to members of the Army, Navy, and National Advisory Committee for Aeronautics.

Hydrocarbon Analyses

During the last few years, new methods of analysis for hydrocarbons have been developed, which not only provide accurate results more quickly than the older conventional procedures, but also afford data not previously obtainable. These newer methods require complex and costly equipment such as refractometers, spectrophotometers, and other optical instruments. All hydrocarbon analyses depend primarily upon effective methods of separation; fractional distillation is frequently used, but silica-gel adsorption and other means of segregation are now widely employed. Subsequent determinations of physical properties are necessary, and these determinations become more exacting as demands for accurate data increase. The Bureau laboratories are keeping abreast of the times in the analytical field, as the photographs of present equipment shown in figures 12 to 15, inclusive, will testify. Figure 12 shows a part of the optical laboratory, including the ultraviolet spectrophotometer and the refractometer with accessories. A battery of silica-gel adsorption tubes used in this work is shown in figure 13, and equipment for freezing-point and viscosity determinations are pictured in figures 14 and 15, respectively.

The analytical methods for hydrocarbon analysis used by the Bureau during the last 4 years were described in reports presented at the American Chemical Society meeting in September.16,17/ They have been submitted for publication in Industrial and Engineering Chemistry, as numerous requests received indicate widespread interest in them.

Cooperative Work

During the year, Report of Investigations 3802,18/ which contains the Bureau of Mines Hempel analyses of 248 Oklahoma crude oils, was published. This report was prepared in cooperation with the State of Oklahoma and the American Association of Petroleum Geologists. Reports of Investigations 379619/ and 3820,20/ covering the National Motor-Gasoline Surveys for the Summer of 1944 and the Winter of 1944-45, were published. These represent cooperative work between the Bureau of Mines and the Coordinating Fuels Research Committee.

One of the most important and difficult problems in the aviation-gasoline program is the proper rating of the fuels being produced for the armed forces. In order to obtain more uniformity and greater accuracy in such ratings, the Coordinating Research Council formed a number of regional groups to study engine ratings and to determine means of improving them. The head of the engine-testing work at the Petroleum Experiment Station was selected as the leader of the Tulsa-Bartlesville regional group of 13 laboratories. Starting in October 1944, 20 regional reports and one summary report21/ were prepared and distributed. These reports have received national recognition.

16/ Thorne, H. M., Murphy, Walter, and Ball, John S., War Research Report on Aviation Gasoline and Component Hydrocarbons. Determination of Aromatics in Light Petroleum Distillates by the Use of Specific Dispersion between the Sodium D Line and Mercury G line, PCR 44-006: May 1944, 23 pp.

17/ Gooding, R. M., Adams, N. G., and Rall, H. T. War Research Report on Aviation Gasoline and Component Hydrocarbons. Determination of Aromatics, Naphthenes, and Paraffins by Refractometric Methods, PCR 44-009: June 1944, 41 pp.

18/ Blade, O. C., Analyses of Crude Oils from Some Fields of Oklahoma. III. Additional Analyses: Bureau of Mines Rept. of Investigations 3802, 1945, 139 pp.

19/ Blade, O. C., National Motor-Gasoline Survey, Summer 1944: Bureau of Mines Rept. of Investigations 3796, 1945, 28 pp.

20/ Blade, O. C., National Motor-Gasoline Survey, Winter 1944-45: Bureau of Mines Rept. of Investigations 3820, 1945, 27 pp.

21/ Tulsa-Bartlesville Regional Exchange Group. Analysis of Rating Data on Samples TB-1 to TB-10, inclusive. Prepared by C. R. Sponsler and B. H. Eccleston, March 1945, 6 pp., 21 tables, 14 figs.

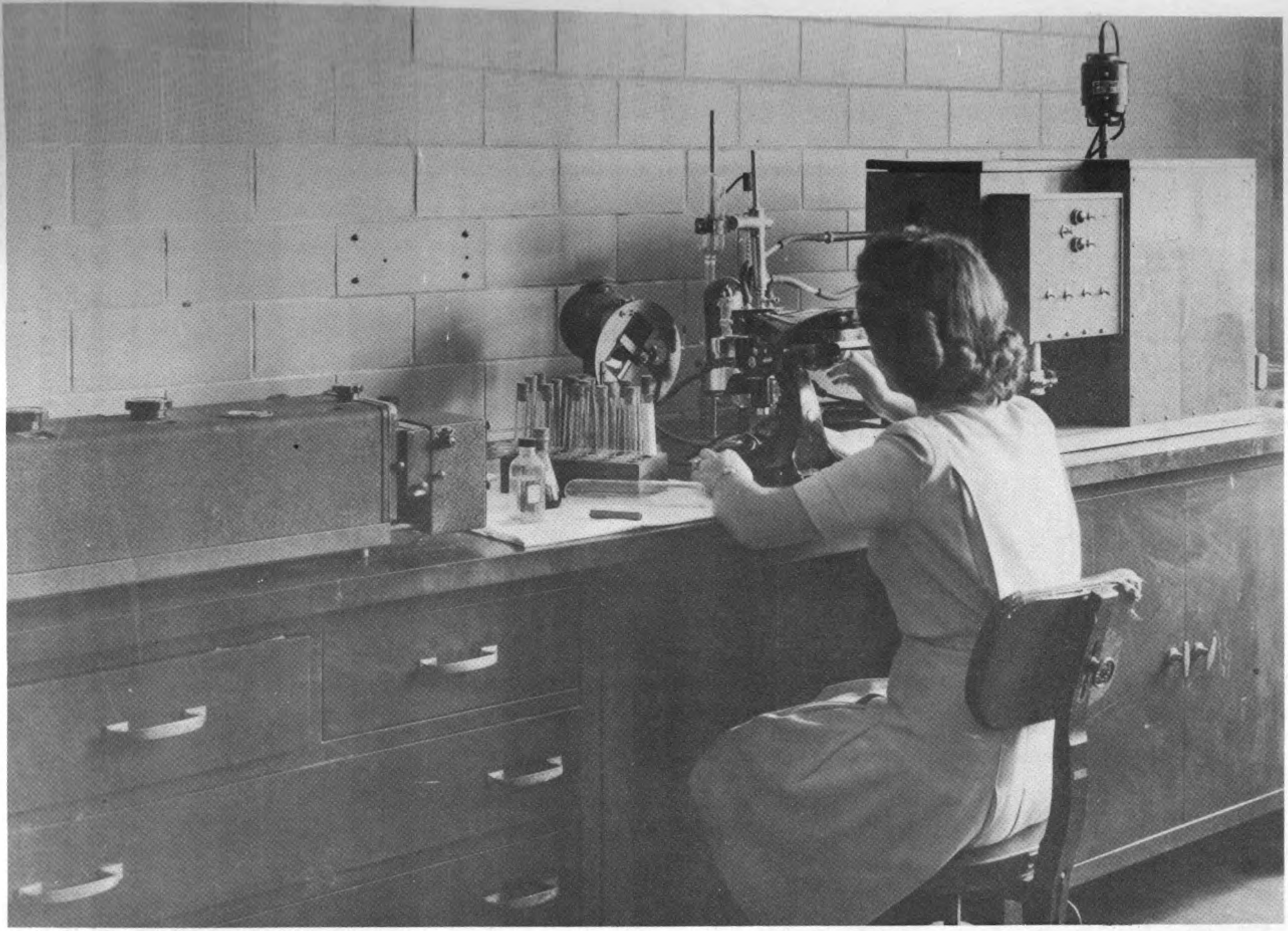

Figure 12. - Ultraviolet spectrophotometer (left) and refractometer with accessories (right) used to analyze hydrocarbon mixtures by optical means.

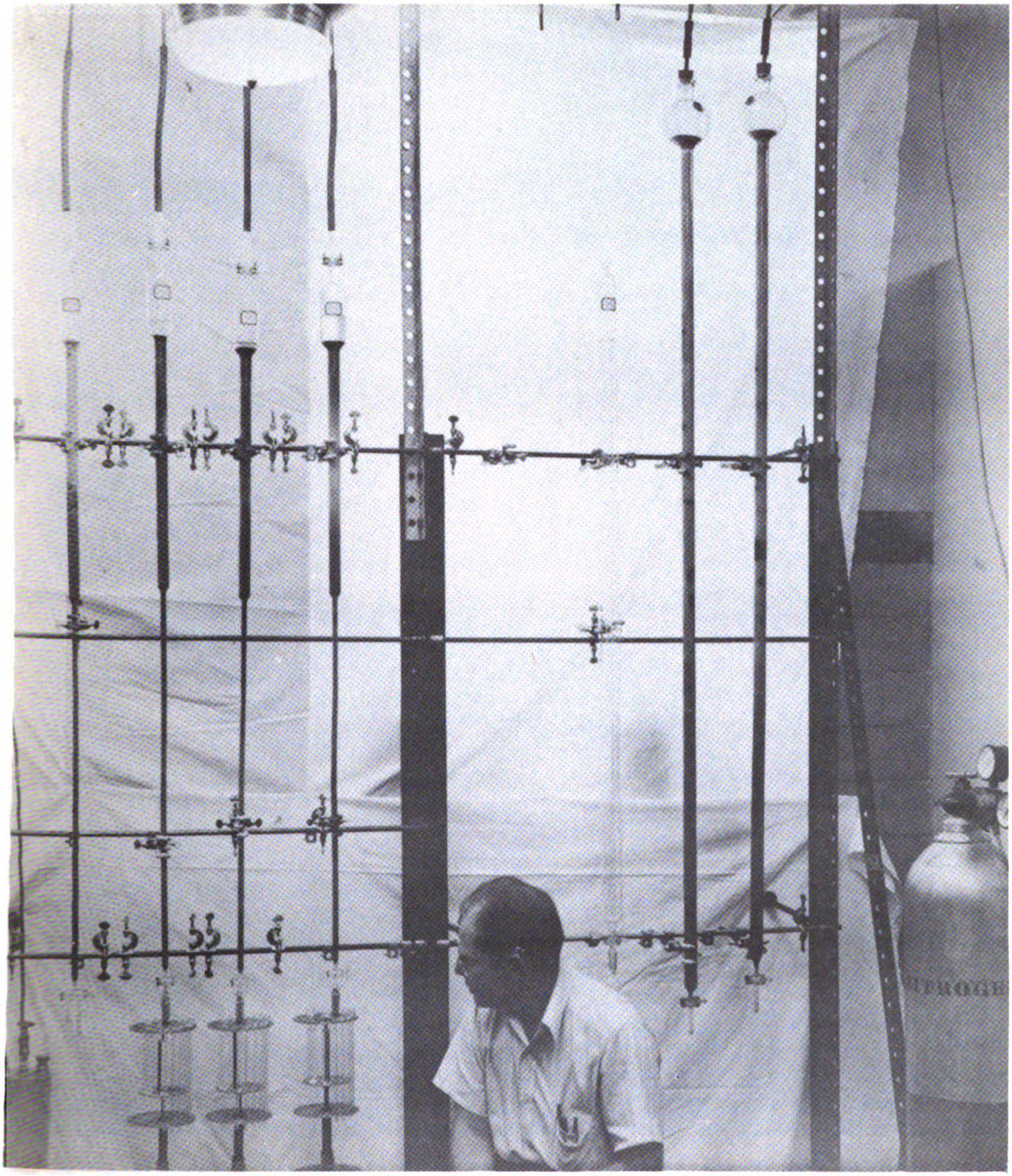

Figure 13. - A battery of adsorption tubes used to separate aromatic hydrocarbons from gasoline and other liquid distillates by filtration through silica gel. Nitrogen under pressure is used to force the liquids through the apparatus.

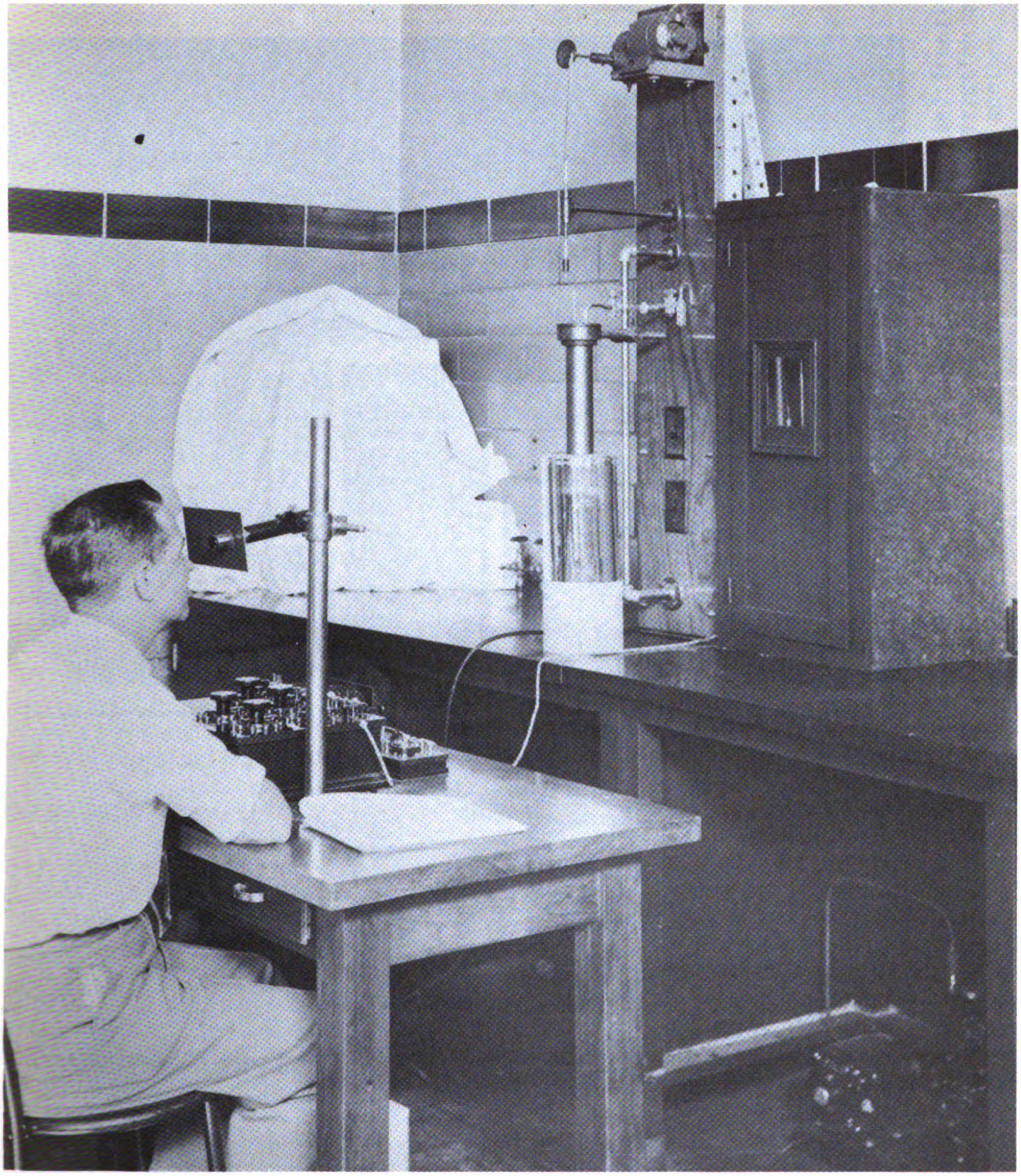

Figure 14. - Apparatus for precise determination of freezing points of hydrocarbons. The freezing tube containing the sample is partly immersed in a glass vessel cooled with liquid air. The operator is obtaining temperature readings with a galvanometer, and the resultant data will be used to estimate the purity of the sample.

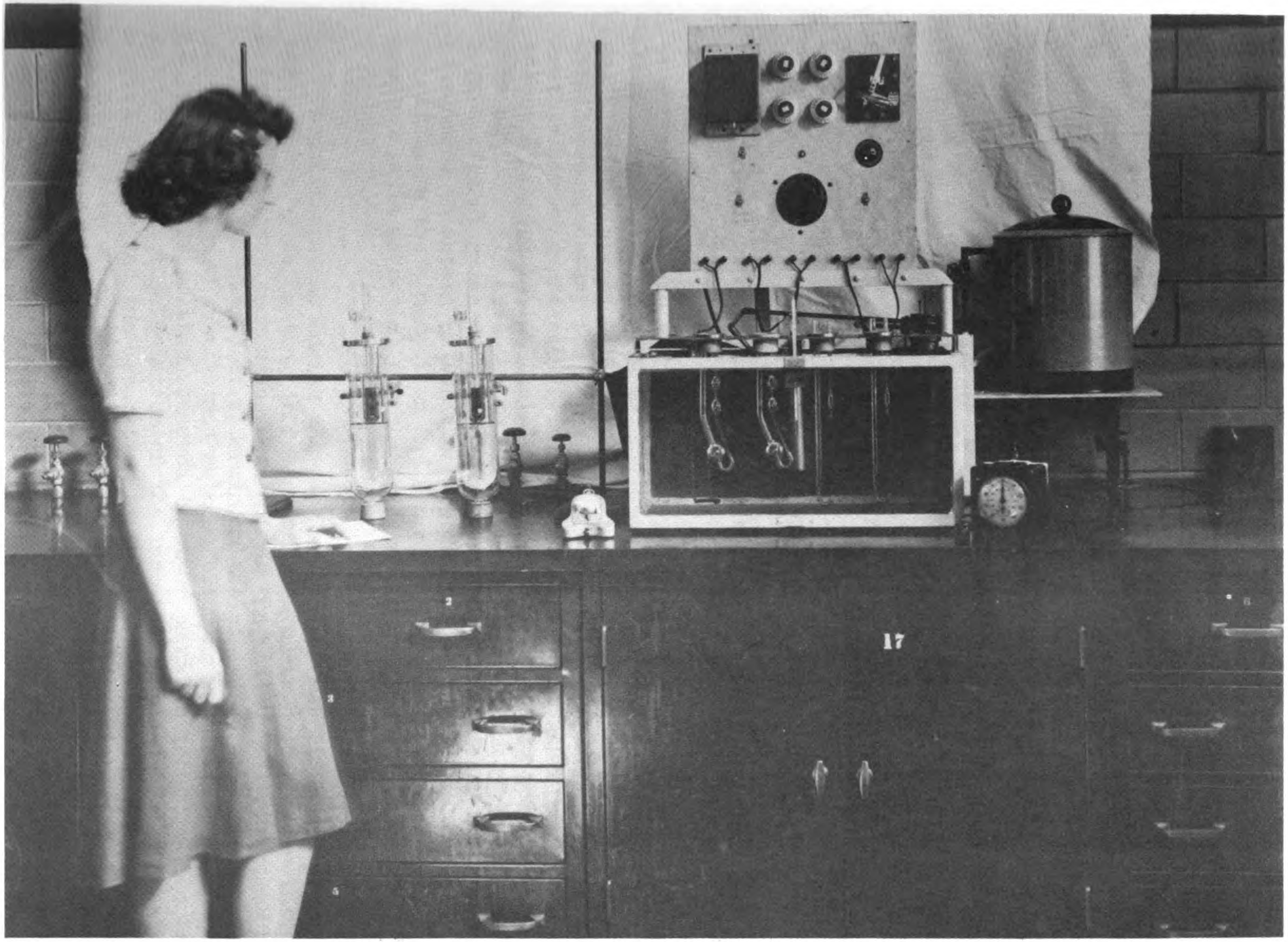

Figure 15. - Apparatus used to determine the viscosity of light petroleum products (in bath) and freezing points of gasoline (operator's left). The viscosimeter bath is controlled to a fraction of a degree by auxiliary equipment. In the freezing-point apparatus, "dry ice" and acetone lower the temperature to -76° F.

There has been active cooperation with the Subcommittee on Hydrocarbon Analysis of ASTM Committee D-2 in many tests to determine the applicability of various methods of hydrocarbon analyses. In turn, several methods for cooperative testing have been proposed. Active work also has been done with ASTM committees dealing with aniline point and lamp sulfur determinations.

Sulfur-in-Petroleum

Realizing the importance which sulfur-bearing crude oils may have in the future petroleum economy of the country, the Bureau has prepared a comprehensive program of research on sulfur compounds in petroleum. The preparation and characteristics of pure sulfur compounds will be studied, and their behavior under different conditions of petroleum processing and utilization will be determined. As the first part of this program, the reactions of these compounds in desulfurizing units employing bauxite and other catalysts and in internal-combustion engines, particularly when tetraethyl lead is present, are being investigated at the Laramie and Bartlesville experiment stations. The cooperation of many petroleum refiners in this project appears probable.

Asphalts from Wyoming Black Oils

Petroleum asphalts as binders in road, airport, and landing-field construction are restricted by Government order to essentially military installations; however, special asphaltic products are being utilized extensively to replace more costly and critical materials used in the manufacture of numerous industrial products. For many of these special uses the compositions and characteristics of the asphalts must be controlled more rigidly than was considered necessary for asphalt binders used in the construction of all-weather paving surfaces. Owing to the shortage of certain crude oils and adequate transportation facilities, asphalts are being prepared from crude oils not formerly used for this purpose. It is also recognized that asphalts from different crude oils have different characteristics, which may have to be altered to obtain satisfactory products. Accordingly, more complete information on the composition and characteristics of asphalts from different crude oils is essential for the preparation of asphalts possessing the desired characteristics.

Asphalt studies during the past year have been directed toward developing methods of separating different amounts of asphalt samples into groups of hydrocarbon constituents and determining the yields and properties of these constituents. A method of determining the yields of asphaltenes, resins, and oils in petroleum asphalts and related bitumens was developed, which overcomes many of the difficulties observed in other proposed methods. The developed method involves the isolation of the insoluble asphaltenes by extraction with normal pentane and the separation of the pentane-soluble resins and oils by the adsorption of resins on anhydrous alumina. Advantages of the method are (1) the short time required to complete an analysis (a determination can be completed in 1 day after sample is allowed to stand overnight), (2) the fractions are isolated to permit the direct determination of yields and other properties, (3) the possibility of oxidation of fractions is reduced, (4) chemical compounds of reproducible properties are used as solvents and adsorbing agents rather than mixtures of materials having variable properties, and

(5) the extractions are made at specified temperatures rather than at the boiling temperatures of solvents, which vary according to barometric pressures.

Laboratory work was completed on the composition, in terms of asphaltenes, resins, and oils, and properties by common asphalt tests of 128 asphalts prepared from 27 crude oils of Wyoming, Arkansas, Montana, Utah, California, Mexico, and Canada. A report on these data is being prepared for publication.

Postwar Plans

Finally, it is emphasized that the work described in the foregoing section was begun before the war; that most of the data obtained as a result of wartime expansion will be applicable to the postwar petroleum industry; and that the future work of the Bureau in petroleum chemistry and refining will not need significant alteration in continuing to serve the nation efficiently. The only modification necessary will be a shift of emphasis from one particular product to another - from aviation gasoline to motor fuel. The same general type of research and the same equipment will serve advantageously in postwar research.

A consideration of postwar activities in refining was prepared as a report[22] for the Special Senate Petroleum Committee under the chairmanship of Senator Joseph C. O'Mahoney and was presented at hearings of that committee.

THERMODYNAMICS OF PETROLEUM

During the past year, investigations were carried on in three fields of thermochemical research, discussed below.

Heats of Combustion

The experimental method consists in burning the compound in an atmosphere of oxygen at high pressure and accurately determining the energy liberated. The quantity so obtained gives the calorific value of the compound. Calorific values may be combined with other data to give thermodynamic functions that are useful in the study of chemical reactions. Determinations were made of the heats of combustion of benzene, n-propyl benzene, and isopropyl benzene.

Lead tetraethyl is used widely as an antiknock substance in gasoline (both in aviation and in motor fuels), and it is extremely important, therefore, to know something of its thermodynamic properties. Research was begun to determine its heat of combustion. As the compound contains lead, it yields oxides of lead when burned, which must be determined by the methods of analytical chemistry. The first approach to this problem has been to work out the analytical methods required and to find the proper conditions to carry out the reaction in the combustion bomb. This part of the investigation has been accomplished. Also, considerable time and study were devoted to devising methods for determining heats of combustion on halogenated

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[22] Smith, H. M., and Ward, C. C., New Uses and Applications of Petroleum: June 1945, 16 pp.

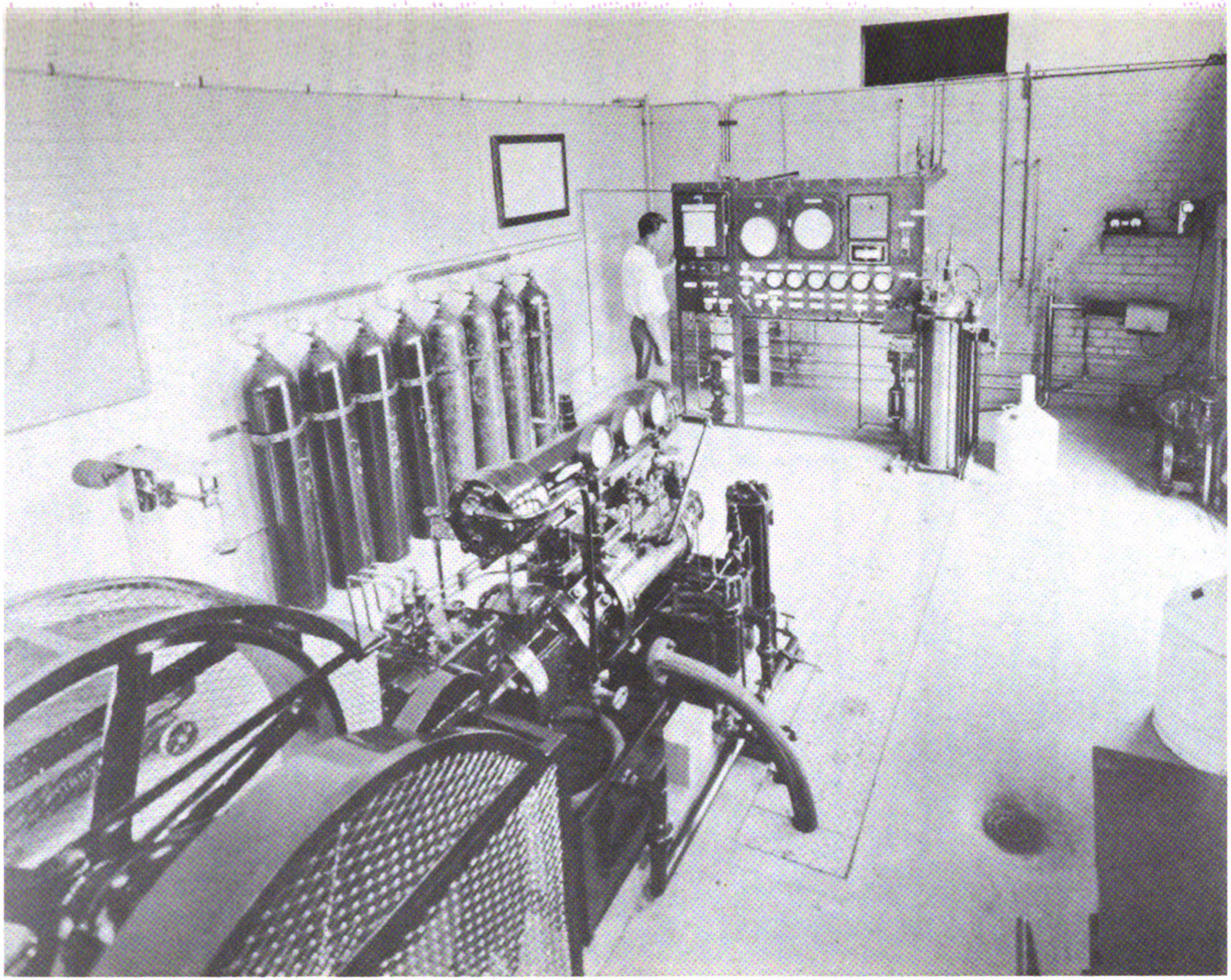

Figure 16. - General view of hydrogen liquefier assembly.

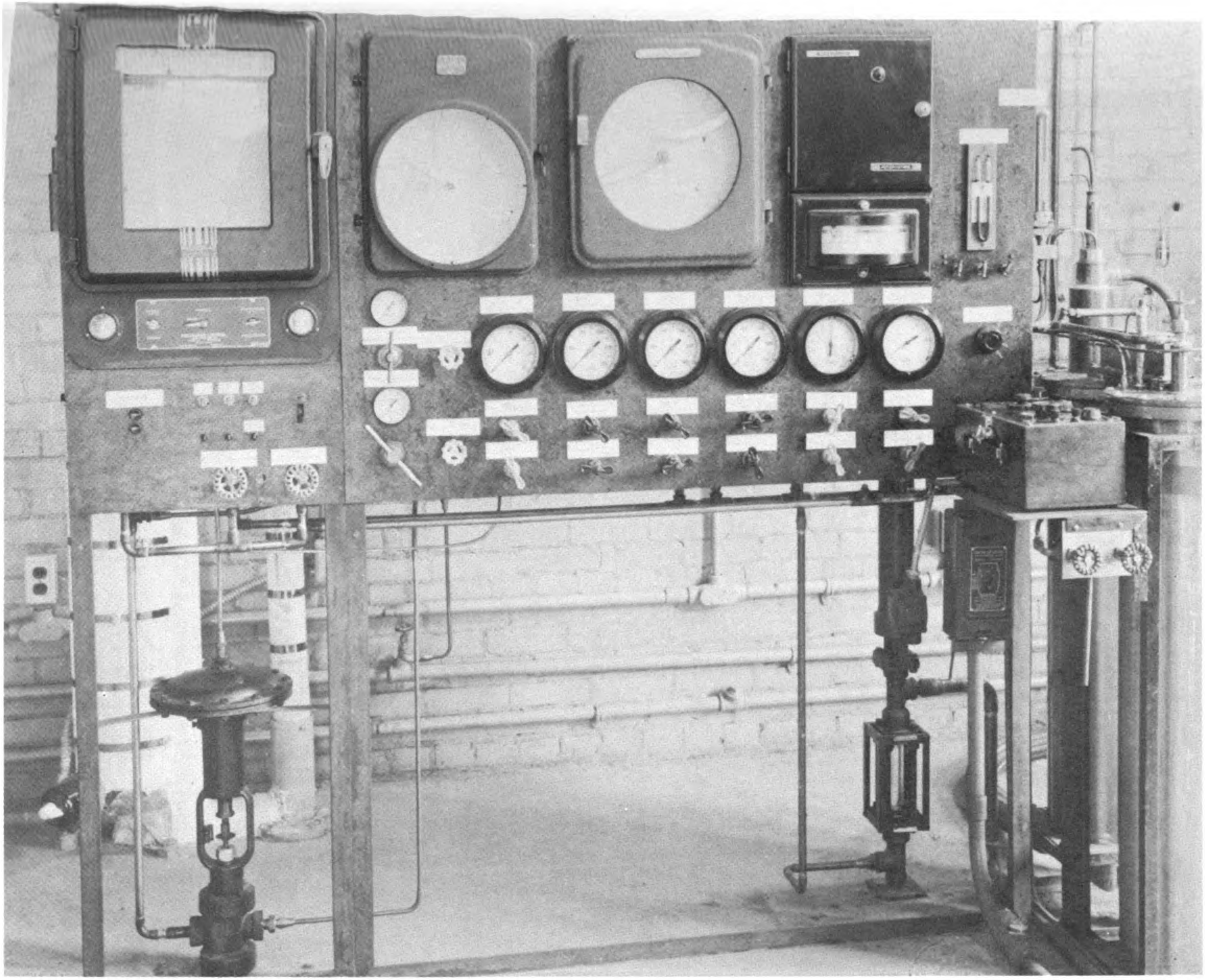

Figure 17. - Close-up of control panel showing instruments and valves that direct the flow in the complicated piping system.

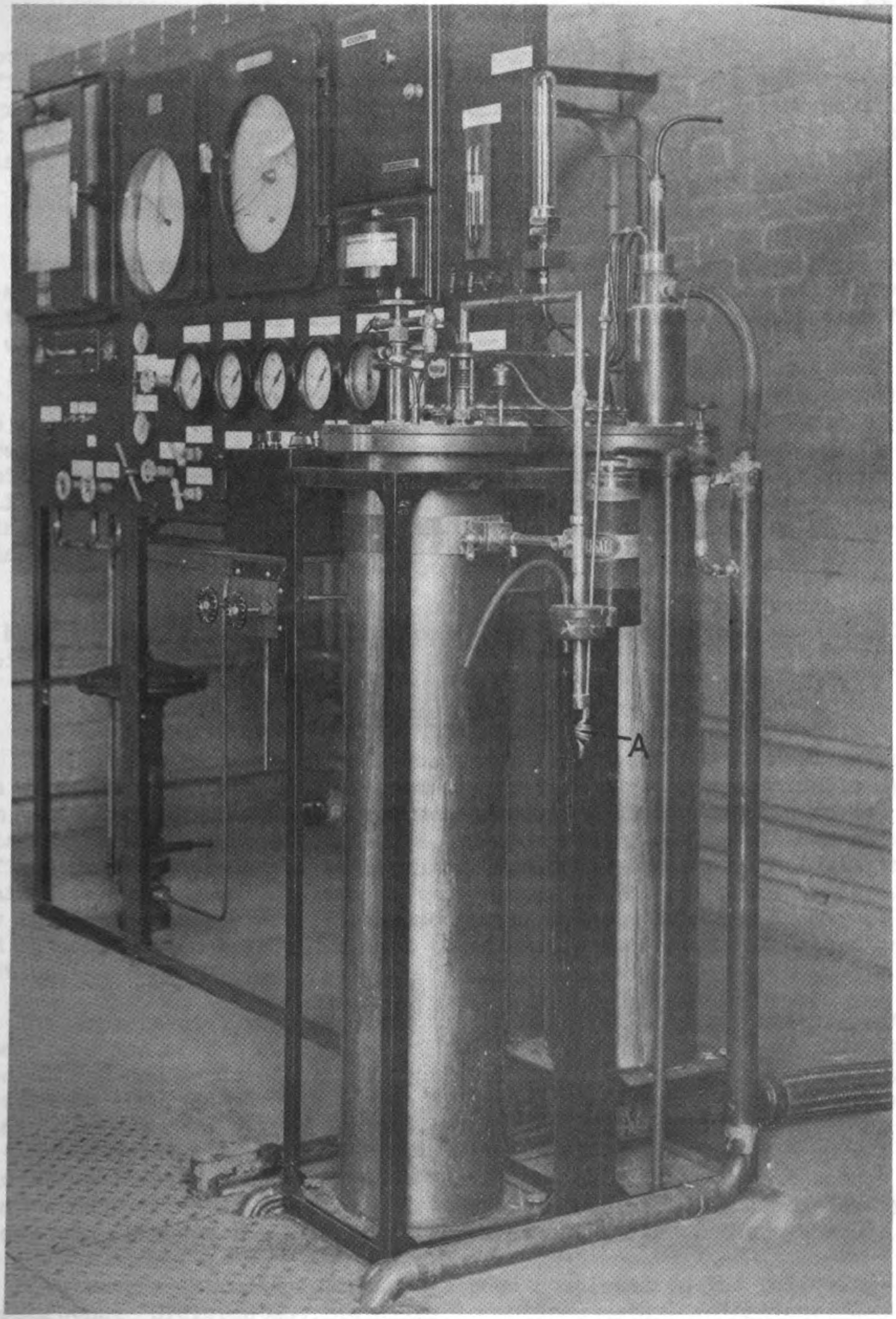

Figure 18. - Assembled hydrogen liquefier, which actually is a specially constructed heat-interchanging system. The liquid hydrogen is drawn from the expansion chamber through a vacuum-insulated transfer tube shown at A.

compounds. The process of burning these compounds offers considerable difficulty because of the presence of the halogen atoms, but satisfactory progress was made. Finally, heats of combustions were determined on six test blends for jet-propulsion fuels in connection with other work on these fuels at the Bartlesville station.

Flow Calorimetry

As a great many chemical processes are carried out in the gas phase and at elevated temperatures, it is necessary to have thermodynamic data for these conditions. In fact, at the present time these are the conditions for which the fewest data are available.

Equipment for determining the heat capacity of vapors in the temperature range of approximately 50° to 200° C. has been set up and is being operated. Here, again, the experimentally determined quantities may be combined with others to yield thermodynamic functions that are of great utility to the chemical engineer. The methods available require painstaking care in regard to experimental details and yield high-quality results only slowly.

Studies have been completed on one hexane (2, 2-dimethylbutane) and one heptane (2, 2, 3-trimethyl butane). The results obtained were highly precise and are believed to be very accurate.

Low-Temperature Calorimetry

In these investigations, measurements are made of the thermal properties of a compound from as low temperatures as are reabily obtainable up to room temperature or higher. These measurements include specific heats, heats of transition, heats of fusion, and the determination of temperatures of fixed points such as melting points. One of the uses for the data thus obtained is for the calculation of the entropy of the compound. This quantity is particularly useful in thermodynamic calculations, as it may be used in conjunction with other data to determine the extent of a chemical reaction.

The experimental work requires the precise and accurate measurement of temperature and of the quantities of electrical energy involved. The lowest temperatures are produced by evaporating solid hydrogen under vacuum. For the work to cover an adequate range of temperatures, therefore, it was necessary to install a system for the production of liquid hydrogen. The plant was completed in December 1944, and the first liquid hydrogen was produced on January 2, 1945. Since that time, the liquefier has been operated many times with very little trouble, considering the complexity of the system. Figures 16, 17, and 18 show various parts of the system.

Low-temperature measurements have been completed on the following hydrocarbons: Cyclopentane, methylcyclopentane, methylcyclohexane, 2-methylpentane, and 2, 3-dimethylbutane. In addition, incomplete data have been obtained on 2, 2-dimethylbutane, 3-methylpentane, benzene, and hexamethylethane. Also, a number of calorimeters have been constructed, and three of them have been calibrated over the temperature range 12° to 300° K.

Complete thermodynamic data on hydrocarbons include measurements of their pressure, volume, and temperature relationships, and some preliminary work has been started on the development of such a laboratory study. This includes a literature survey and a tentative design of equipment to carry out the experimental work. It should be stressed that these measurements are of fundamental importance, as no real material behaves ideally, and many reactions are carried out at elevated temperatures and pressures. Data of this kind will permit the engineer and chemist to predict the proper conditions under which a given reaction should be carried out and also to calculate the maximum yields expected from the reaction.

HELIUM PRODUCTION

Helium production statistics still can not be released, for security reasons, but the continued success of the Division's helium-producing section is attested by continued recognition from the Army and Navy. The Otis Helium Plant received the coveted Army-Navy "E" award, and the Amarillo and Exell plants each were awarded a star to add to "E" awards already received. Also the guard forces at the Amarillo and Exell helium plants each received the "Auxiliary Military Police Award of Merit" guidon for faithful and efficient performance of duties.

The demand for helium during fiscal year 1945 was reduced considerably below previous estimates owing, first, to the winning of the anti-submarine battle in the Atlantic and finally to the victory in Europe. This reduced demand caused two major retrenchment steps to be taken in helium production operations. First, the Navajo Helium Plant, which was built to process helium-bearing natural gas from the Rattlesnake field (New Mexico), was placed in a standby status. Second, and for the first time in history, the Bureau was able to begin a program of conservation of this vital element. Helium contained in natural gas available for processing by the Exell Helium Plant and which, if not extracted, would have gone to fuel markets and been forever lost has been extracted and injected into the Government-owned Cliffside gas field, which supplies natural gas to the Amarillo Helium Plant.

This conservation was made possible by the completion of a small-diameter, high-pressure pipeline connecting the Exell and Amarillo Helium Plants and the Cliffside gas field. The Cliffside field is a wholly owned Government helium reserve and is used as needed to supply helium-bearing natural gas to the Amarillo plant. The Exell plant processes natural gas from a commercial pipeline system supplying a large fuel market. The amount of helium saved during the year by injection into the Cliffside field exceeded by more than 20 percent the total amount of helium produced in any prewar year.

The commercial sale of helium to non-Federal users increased more than 50 percent above the total of such sales during the fiscal year 1944. This rapid increase is indicative of a greater public knowledge and acceptance of the uses to which helium may be put. It continues to receive favorable reception in the welding of magnesium and other light metals, in providing artificial breathing atmospheres in diving operations, and in the treatment of respiratory diseases, as a diluent to prevent the explosion of anesthetics in operating rooms, and more recently as a tracer gas to follow the movement of gases injected into oil-bearing formations.